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Technical Report

INDUSTRIAL APPLICATION OF VOLCANIC MATERIALS IN ICELAND

Report prepared for the Government of Iceland
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INDUSTRIAL APPLICATION OF VOLCANIC MATERIALS

FINAL REPORT

about the expert activity performed in Iceland on behalf of UNIDO from 3 August to 2 November 1975 concerning the project "*Perlite Based Building Materials*"

by

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This Final Report contains the activity of J.E. Ujhelyi, performed in Iceland from 3 August to 2 November. The expert feels himself bound to express his thanks for the kind aid of the Icelandic Government and colleagues, without that his job would not have finished with result. He is much obliged to

Mr. Sveinn Björnson, Director, IMSI	Mr, Hörður Jónsson, Chairman of VMC, IMSI
Mr. Pétur Sigurjónsson, Director of IRI	Mr. Haraldur Ásgeirson, Director, BRI
Mr. Ottar Halldórson, Prof. in University	Mr. Haraldur V. Haraldsson, Architect
Mr. Aðalsteinn Jónsson, Chem.Eng.	Mr. Gylfi Einarsson, geologist
Mr. Sigmundur Einarsson, geologist	Mr. Gáspár Tahy, UNIDO expert team leader

for favouring his efforts

1. PRELIMINARIES

This report presents an account of work carried out in Iceland from 3 August to 2 November 1975 under a UNIDO assignment on industrial application of different volcanic material in collaboration with the Government of Iceland, Ministry of Industry. According to the "Job description" the purpose of project was to provide aid in a number of specific fields related to the explication of the volcanic material.

Specifically the expert was expected to:

1. plan and assist in the execution of trial productions of various perlite based building materials for the Icelandic market, in particular perlite gypsum wallboards, perlite insulating mats and loose perlite, insulating mortar, perlite concrete (boards, panels and loose), bituperl, hydrophobic perlite, sound insulating boards and tiles etc.;
2. supervise the installation tests with the produced building materials to asses consumer acceptance and decide on realistic product selection;
3. assist in the preparation of feasibility studies and investment proposals for the recommended manufacture where applicable;
4. examine the Icelandic deposits of pumice and asses the quality of the raw material;
5. evaluate the possibilities of utilizing the pumice in building materials such as lightweight concrete and propose suitable ways of implementing such utilization;
6. assist in preparing an investment proposal related to the explication of pumice;
7. advise on any other activity within this field of competence.

According to the above the job description did not mentioned the participation in investigation of Icelandic scoria. But based on the own experience of the expert which was get at his last work in Iceland on the one hand and with reference to the substantive briefing in Vienna (discussion with Mr. G.C. Verkerk) on the other, the expert also prepared the research of scoria utilization.

2. DETAILED PROGRAM OF EXPERT ACTIVITIES

The expert of UNIDO appointed to this job arrived at Iceland on 6 August 1975. After preliminary discussion with the members of Volcanic Material Committee, he went to Akranes – where the perlite expanding plant would be operated – to control the progress of construction. In the same time arrived at Akranes the mounting-leader of firm making the expanding equipment, therefore they were able to determine the presumably term of finishing the mounting. This term determined the program of the UNIDO expert, he had to state that – in tree months – only the preparative work can be performed, i.e. training the Icelandic counterpart, making aggregate investigations and drawing up the detailed program of utilization of Icelandic materials (perlite, pumice and scoria).

Making the program, the tasks written in the job description of UNIDO and the requirements of the Icelandic counterpart were taken into consideration. The program was as follows:

4. – 8. August

- briefing in Vienna at UNIDO
- preparing discussion on the requirements of the Icelandic counterpart and the UNIDO team leader in Reykjavík as well as surveying the preparation of perlite plant at Akranes.

11. –15. August

- surveying different lightweight material deposits in the South-West of Iceland and indicating the territories from which samples should be transported to the Building Research Institute at Keldnaholt;
- preparing the program of the expert for three months and discussing it with the Icelandic counterpart and the UNIDO team leader.

16. – 22. August

- training the Icelandic colleagues appointed to participation and assistance in investigations on perlite, pumice and scoria, teaching testing methods and concrete technology in general;
- beginning the investigations in Keldnaholt on lightweight aggregate samples collected from different deposits.

25. – 29. August

- directing investigation of lightweight aggregate properties;
- to continue training and for this purpose to compile paper with title: *"What to know about lightweight aggregate concrete?"*. This paper contains the most important knowledges of lightweight concrete technology on the one hand and the detailed program of scoria and pumice investigations on the other.

1. – 5. September

- directing investigation of lightweight aggregate and teaching the evaluation methods of results;
- drawing up the lists of perlite products which should be manufactured in pilot plant at Keldnaholt, designing the products and the technology (equipment, moulds, curing, additive materials etc.) of pilot plant manufacturing in collaboration with the Icelandic counterpart;
- compiling paper: *"What to know about lightweight aggregate concrete?"*.

8. – 12. September

- after having evaluated result of aggregate testing, the expert signs the suitable aggregates for technological investigations;
- finishing paper: *"What to know about lightweight aggregate concrete ?"* together with technological research program of Icelandic pumice and scoria;
- compiling paper: *"Program of perlite investigations on laboratory and pilot-plant scale"*.

15. – 19. September

- compiling paper, together with Icelandic colleagues: *"Report about investigations on Icelandic pumice and scoria. Results of aggregate investigations"*;
- finishing paper *"Program of perlite investigations on laboratory and pilot plant scale"*.

22. –26. September

- finishing paper together with Icelandic colleagues: *"Report about investigations on Icelandic pumice and scoria. Results of aggregate investigations"*;
- investigation of hydraulic effects of pumice and scoria..

29. September –3. October

- revision and correcting of type-scripts, their preparation for multiplying;
- discuss with member of Volcanic Aggregate Committee and UNIDO team-leader about proposals of papers.

6. – 10. October

- drawing up the exhibition in Iceland of perlite and different perlite products for marketing purposes;
- discus with member of Volcanic Aggregate Committee and UNIDO team-leader about exhibition proposals;
- compiling the Final Report of the expert.

13. –17. October

- technical discussion about papers: *"What to know about lightweight aggregate concrete?"; "Program of lightweight aggregate investigations"; "Program of perlite investigation on laboratory and pilot plant scale"* and *"Report about investigations on Icelandic pumice and scoria"*;
- compiling the Final Report of expert.

20. – 26. October

- finishing the Final Report of expert;
- finishing the investigations of hydraulic effect of pumice and scoria.

27. – 31. October

- final discussion about the activity of experts and its results;
- debriefing in Vienna at UNIDO.

3. ACTIVITY OF THE EXPERT IN ICELAND

Activity of the expert was accomplished on the basis on the basis of detailed program (see Chapter 2.). The minute accounts can be found as appendices of this Final Report:

Appendix 1 : *What to know about lightweight aggregate concrete ?* Included: *Investigation program of Icelandic lightweight volcanic materials.*

Appendix 2.: *Program of perlite investigations on laboratory and pilot plant scale.* Included: *Proposal for exhibition of perlite and perlite products.*

Appendix 3.: *Report about investigations on Icelandic pumice and scoria.*

In respect of job description, the expert carried out the following activity:

ad 1. Since the perlite expanding plant at Akranes was not completed during the staying of expert in Iceland, he summarized the processing methods and products to be made for the Icelandic market and his proposals were discussed with members of Volcanic Committee. The summarizing was compiled with all details are needed to making different perlite products, e.g. perlite wallboards, perlite heat-insulating mortar, perlite concrete etc. (see Appendix 2). With Icelandic counterpart signed to assistance in perlite production, the expert made more practical investigations to determine the effect of mixing ratio and technological process. Specimens made in the course of the investigations have to be tested in November by Icelandic geologists participating in training.

ad 2. In paper of appendix 2 the expert summarized the realistic products selection to assess consumer acceptance and suggested to mounting an exhibition of different perlite products.. After having discussed this suggestion, the Volcanic Material Committee have decided to arrange this exhibition in the next year (presumably on April 1976) when the expanding plant in Akranes produced already suitable quantity of expanded perlite. Since this plant will be put in operation during this November, the fixed date seams to be convenient.

ad 3. The expert had assisted in the preparation of feasibility studies and investment proposals made by UIDO team-leader and Icelandic counterpart.

ad 4. The expert had examined the Icelandic deposits of pumices and scoria, results and proposals are summarized in Appendices 1 and 3.

ad 5. The expert evaluated the possibilities of utilizing the pumice and scoria in building industry such as lightweight aggregate and proposed suitable ways of implementing such utilization (see Appendices 1 and 3).

ad 6. The possibilities of investigations were limited, therefore the work on field pumice and scoria utilization did not attain the level required for preparing an investment proposal. This proposal can be compiled if the possibilities of investigation are arranged and the results are at disposal.

ad 7. The expert participated in more discussion within this field of competence,

4. SUMMARIZING RESULTS OF EXPERT ACTIVITY

4.1. Perlite

On the field of perlite using the expert made investigations with together the Icelandic counterpart. The investigations were carried out with perlite expanded in the small laboratory testing-furnace. The goal of this work was training the Icelandic geologists. It can be stated that this training had full success since the Icelandic counterpart have carried out testing also without control and with good results. Therefore perlite expanded in pilot-plant furnace can be investigated in laboratory scale without any expert activity (see Appendix 2, Chapter 1.).

The expert compiled a paper with detailed Figures for carrying out the pilot plant investigations. On the basis of this paper one part of the work (using loose perlite, perlite mortar for wall insulation, perlite for pipe insulation, masonnary units, hydrophob perlite for water cleaning) can be performed without expert, but the other part of it needs expert activity (perfabricated or in-situ made perlite concrete elements).

Advised exhibition had been accepted by the Icelandic counterpart and it is supposed to organize in the second quarter of the next year (April - Mai 1975). To determine the exhibited products and to make them, expert activity is needed.

4.2. Lightweight aggregate

On the field of using pumice and scoria the expert compiled a paper about the most important knowledges of lightweight aggregate concrete and proposed program of detailed investigations (se Appendix 1). In the recent situation he was not able to get laboratory possibilities for carrying out the whole program because of shortage of labour, but the material properties of 16 samples could be tested together with the Icelandic counterpart. The results were summarized in Report (see Appendix 3) and they allowed to reach conclusions.

The report and the suggested research work were discussed in a meeting on 23 October 1975 convened by IMSI (Industrial Development Institute) and Volcanic Material Committee. After having debated the results and proposals the participants agreed with the suggested research work, It seems that these laboratory examinations can be carried out in the next year. Though the papers (Appendices 1 and 3) give satisfactory summary about the lightweight aggregate concretes and their using, nevertheless expert activity is needed for performing the research.

The testing of 15 samples proved that Iceland has many good and a few excellent lightweight material. The Icelandic counterpart agreed that these materials shall be used in Iceland in the building industry and on the basis of results it is advisable to prepare also for external marketing. Furthermore the Icelandic counterpart agreed that the internal using has to precede the export therefore the research would be started with investigations for solving the local problems.

In the local market choice of materials to be used depends manly on transport prices therefore deposits located near the territory of use have to be taken in account. Materials of very good quality but in deposits far away will be used only in special cases (e.g. in structures of bigger span) and perhaps for export purposes.

5. PROPOSALS

5.1. After having expanded perlite in pilot-plant furnace every expanded ort has to be investigated in laboratory (see Appendix 2) to determine its properties. The method of expanding to be applied can be decided after these investigations.

5.2. When expanded perlite of about100 m^3 is at disposal, the pilot plant production has to be started for using on the one hand and for exhibition on the other, The exhibition is needed for internal marketing.

5.3. After having had perlite products for using and exhibition, the external marketing of ground and classified raw perlite can be increased, because these products can serve as references.

5.4. During the expert activity lightweight materials of south-western territory of Iceland were tested. It seems to be necessary to search lightweight materials of northern and eastern territories of Iceland, where there is significant building activity. These materials shall be investigated according to Appendix 3.

5.5 Materials located near to building centers on the one hand and of very good quality on the other shall be fully investigated according to Appendix 1. On the basis of results constructions and products can be designed for internal using and external marketing can be started as well.

5.6 On the basis of investigations results and designed products, the necessary equipments for production can be estimated, the feasibility study of lightweight aggregate concrete industry can be made.

APPENDIX 1

WHAT TO KNOW ABOUT LIGHTWEIGHT AGGREGATE CONCRETE ?

by János Elemér Ujhelyi, Civil Eng., Ph.D., UNIDO expert

REYKJAVÍK, August 1975.

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This paper was written to outlining the mot important information about lightweight aggregate concretes. Its purpose is only to give basis for testing Icelandic natural lightweight materials for colleagues who will be working on this field in the future and will finish the research begun in August 1975 under guidance of UNIDO expert.

1. INTRODUCTION

Generally laymen think that making concrete is very easy business. We only have to mix cement, aggregate and water, then compact this mixture into a mould and wait until it is hardened. This mixture will be concrete but you may rest assured that it won't be a good or economic one.

The concrete will be good when its properties meet the technical requirements and economic when it is done by the cheapest materials and most simple technology.

First we shall survey the technical requirements.

The most important properties of concrete – and not only that of lightweight aggregate concrete – are generally its density and compressive strength. Of course there are also many important properties but usually these are in close connection with the compressive strength or with the density. Such properties are the flexural strength, the water absorption, the freezing resistance, the shrinkage, the creeping, the thermal conductivity etc. We shall have talks about these properties at a later date.

The density is the weight of unit volume, its dimension is kg/m^3 (in English: lb/cuft, 1 kg/m^3 = 16 lb/cuft). The density can be measured under different conditions: immediately after compacting (density of fresh concrete), after 28 days (density at testing) and after drying (density of the dry concrete). The most important data: density of the fresh concrete and density of the dry concrete.

The compressive strength is the load-bearing capacity against the pressing forces controlled with some kind of specimens. In English standards the cylinders are prescribed , some other standards (e.g. the German one) prescribe the cubes to investigate the compressive strength of the concrete. It is very important to know when we read the concrete data what type of specimen was investigated, because a small cube or cylinder from the same material shows higher compressive strength than the bigger one, or a cylinder shows lower strength than a cube of the same height.

In Iceland cylinders of about ∅15x30 cm (i.e. ∅6x12 in) are used to characterize the compressive strength of concrete. The conversion factor between cylinder of 15x30 cm and cube of 20x20x20 cm I generally:

compressive strength in cube = 1,2 x compressive strength of cylinder

The dimension of compressive strength is in English literature: psi (lb/sqin), in continental literature: kp/cm^2 or Newton (N). The conversion factor:

$$1\ kp/cm^2 = 0{,}1\ N = 0{,}07\ psi$$

Let's look now very shortly at the process of manufacturing concrete.

First we have to choose the most suitable materials, i.e. cement, aggregate and – by chance – additives , prepare them in a satisfactory way and measure their necessary quantities by weight. Then we put them into a mixer and mix with water of necessary quantity during a necessary period. After mixing we transport the mixture to the working place, put into the mould and compact it with suitable compacting machine during a satisfactory period of time. We cure the compacted concrete in a suitable way and during a required period of time.

As can be seen in these sentences there are more attributives: suitable, satisfactory, necessary etc. These attributives indicate the parts where we have to pay attention to our activity, because at these parts we have to act under certain rules. By means of these rules we can influence and regulate the density and the compressive strength of concrete.

2. RULES OF MANUFACTURING LIGHTWEIGHT CONCRETE

2.1. We have to choose the most suitable materials

The cement is fine-ground hydraulic binder, 1.e. mixing with water it sets and hardens on air as well as under water. The mixture of cement and water (so called: cement paste) sticks the sand and gravel or other aggregates added to it and this sticked compound will be after its hardening insoluble in water.

The hardening process is the result of hydrolysis and hydration. During hydrolysis the materials of clinker dissolve under the action ions of water, the oxides are transformed into hydroxides. The hydrolysis will be ended when water becomes impregnated with the products of hydrolysis and with Ca $(OH)_2$. During the hydration different hydrosilicates and hydroaluminates come into being. The products of hydration in the hardened cement paste are shown in the following table:

The original minerals of clinker	*The end-products*	
	in formula	in short marks
Trikalciumsilicate	3 $CaO.2\ SiO_2.H_2O$	C_3S_2H
Dicalciumsilicate	2 $CaO.2\ SiO_2.H_2O$	C_2S_2H
Tricalciumaluminate	3 $CaO.Al_2O_3.6\ H_2O$	$C_3A\ H_6$
Tricalciumaluminate+ Gypsum	3 $CaO.\ Al_2O_3\ .3$ $CaSO_6.\ 32\ H_2O$	
from hydrolysis	$Ca(OH)_2$	
secondary product	$CaCO_3$	

In Iceland we are not able to choose cement in practice since there is only one type of it. But it is advantageous to know: the better the cement, the higher the compressive strength of the concrete, It gas to be mentioned that the cement is characterized by its compressive strength of 28 days investigated in mortar-cube or mortar cylinder.

Standards of different countries prescribed different methods for testing cement quality, so that the trade-names of the same cement were different (these trade-names show the compressive strength of cement). Recently the testing method of cement has been unified by ISO (International Standard Organisation): we have to make the cement mortar from 1 part of cement, 3 parts of Standard-sand and 0,5 part of water (by weight), mix this mortar in a Standard-mixer and compact the mixture on a Standard-vibrator. The specimens are 4 x 4 x 16 cm prisms. The compressive strength of the specimens should be investigated in ages 1, 3, 7 and 28 days and the trade-names are as follows (the compressive strength in 28th day): 550, 450, 350, 250 and 200.

In Iceland cement is made of 350 (according to the old Standard it was 500).

-.-.-.-.–

We are able to choose the most suitable aggregate if we know the most important properties of them.

Anyone can see half an eye that the compressive strength of concrete will be high if the aggregate used t it has high strength and the concrete's strength decreases when that of the aggregate decreases. In the same way it is self-evident that the lighter the aggregate the lower the density of the concrete.

The aggregate is in general a granulous material so that its compressive strength cannot be investigated in the usual way: in cylinder or in cube. Therefore another testing method has been developed. This method is as follows:

The grains are put into a metal cylinder so that the grains should be flushed with the upper level of the cylinder (see Figure 1, part a). Then a plunger will be placed on the grains (se Fig. 1, part b) and this apparatus will be set in the testing press. The plunger will be pressed to a prescribed depth (on the top of the plunger is shaped a border) and the necessary force will be measured. The self strength of the aggregate: *F/S in kp/cm²*, where F = the force for pressing the plunger to described depth in kp, S = surface of the cylinder (of the plunger) in cm².

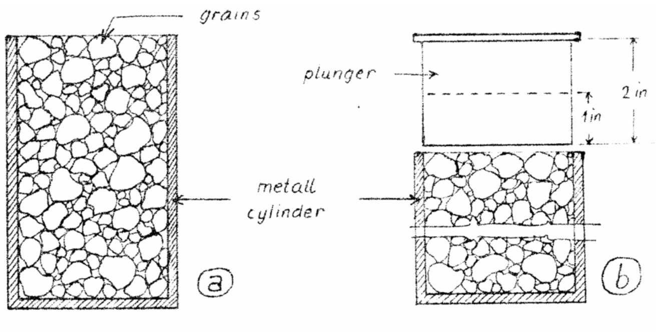


Fig. 1.: Apparatus for testing aggregate self-strength

The sizes of cylinder change in different Standards, e.g. the Hungarian Standard prescribes diameter 12 cm (inside) and height 15 cm, the ASTM prescribes diameter 3 in (~ 7,5 cm inside) and height of plunger is prescribed 25 mm (1 in) or 51 mm (2 in).

There is also another method for testing the strength of grains developed by *HUMMEL* (Hummel'sche Zertrümmerungsgrad, i.e. crumblingfactor of Hummel). Its essence is as follows:

From the aggregate we screen the grains of 7-10 and 10-15 mm and from both fractions we put 50-50 pct by weight after mixing into a cylinder, which has a diameter of 15 cm. The total quantity of the aggregate must be come to 0,5 litre. The grains will be pressed by a plunger with a force of 5000 kp. The material will be screened on sieves of 1, 3 and 7 mm and the residual will be weighed on each sieve. The percentage of each residuum should be calculated and summed, the result of summing should be marked with ***m***. The crumbling factor is: $c_f = 3 - m$

Example: The grains of 7-15 mm of an aggregate have a bulk density of 640 kg/m³ so that 0,5 litre of it comes to 0,32 kg. This quantity of the aggregate was put into thy cylinder and pressed with a force of 5 tons. After screening the crumbled aggregate we got the following results:

residuum on sieve of 1 mm : 0,28 kg ⇒ 88 % ⇒ 0,88
residuum on sieve of 3 mm : 0,24 kg ⇒ 75 % ⇒ 0,75
residuum on sieve of 7 mm : 0,18 kg ⇒ 56 % ⇒ 0,56
m = 2,19

The crumbling factor is : $m = 3 - 2{,}19 = 0{,}81$

This testing method has many advantages:

- the results of investigations made with different grading can be compared with each other;
- the number characterizing compressive strength of the aggregate isn't a quantum without dimension;
- when the numerical value of the testing result increases then the strength of aggregate increases too.

Usually we don't measure the density of the aggregate but its bulk density. The grains will be poured loosely into a cylinder of a determined dimension (in general the volume of the cylinder is 1 or 10 litre) and weighed. If the weight of the empty cylinder is W_c in kg and the weight of the cylinder filled with the grains is W_g in kg, the bulk density of aggregate *(B)* in a cylinder of 1 litre is: $B = 1000 \,.\, (W_g - W_c)$ *in kg/m³*

and in a cylinder of 10 litre: $B = 100 \,.\, (W_g - W_c)$ *in kg/m³*.

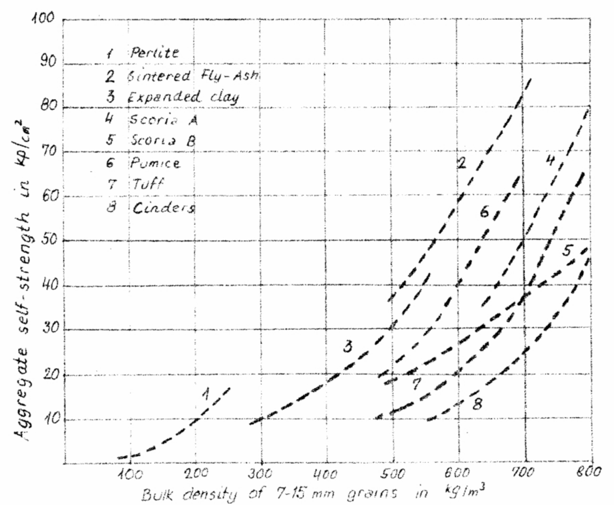


Fig. 2.: Relationship between bulk density and self-strength of Hungarian lightweight aggregates

Between the bulk density and the compressive strength of the same aggregate derived from the same deposit there is a relatively close connection, but this connection does not exist for other aggregates Some data of Hungarian materials can be seen in Figure 2.

But it should be kept to ourselves that it does not necessarily follow that e.g. with a scoria *B* of bulk density 550 kg/m³ can be manufactured concrete of higher compressive strength than with the scoria *A* of the same bulk density though the scoria *B* has higher self-strength than the scoria *A* at this bulk density.

On the other hand it necessarily follows that e.g. with the scoria *B* of bulk density 550 kg/m³ we can manufacture concrete with lower compressive strength than with the same scoria *(B)* of bulk density 750 kg/m³ since the self-strength of the latter is higher.

As mentioned above the self-strength and the bulk density of the lightweight aggregate have great importance, but these are not the most important features of the lightweight aggregate. It is grading which is of greater importance.

The grading means the proportion of the different grain sizes: how much quantity can be found in aggregate of grains of 0-0,1 mm, 0,1-1 mm, 1-2 mm etc. This grain distribution of the aggregate can be illustrated in the so-called grading curve. To make this grading curve determined quantity should be weighed from the average sample of aggregate (e.g. 5000 g) and screened on sieves of 0,1; 0,5; 1 mm etc. Every gain passed through one of the sieves should be weighed and counted in percentage of the total quantity.

a	**b**	**c**	**d**	**e**	**f**	**g**
0,1	250	5	4750	0 – 0,1	250	5
q,5	500	10	4500	0,1 – 0,5	250	5
1,0	1500	30	3500	0,5 – 1	1000	20
2,5	2100	42	2900	1 – 2,5	600	12
5,0	300	60	2000	2,5 – 5	900	18
10	3650	73	0350	5 –10	650	13
20	4300	86	700	10 –20	650	13
30	4850	97	150	20 –30	550	1
40	5000	100	0	30 – 40	150	3
					5000 g	100 %

a sieve size, mm **b** grains passed through sieve, g
c grains passed through sieve, pct **d** residuum on sieve, g
e grain size, mm **f** quantity of grain, g
g quantity of grain, pct

Let's take an example: The initial quantity of the average sample of aggregate: 5000 g. The testing results can be seen in the appended table. The grading curve draw on basis of these data can be seen in Fig. 3.

The grading curves of aggregates give very important information about quality of aggregates. To be able to evaluate this information we have to know some basic rules which determine the properties of concrete. These rules are as follow:

a) The compressive strength of the concrete – among other things – depends on the strength of hardened cement paste. The strength of the cement paste is influenced by the water/cement ratio, i.e. on the relation between the water content and cement content of the cement paste. When the water/cement ratio is high then the strength of the hardened paste is low.

b) The compressive strength of the hardened cement paste is influenced by the density i.e. by the pore content. When the pore content is high, then the strength of the hardened cement paste is low.

c) The pore content of the cement paste is influenced by its workability. When the cement paste is very dry after the mixing, it is impossible to compact it without pores into the mould with the usual vibrators. When the cement paste is very wet, on the one hand it is possible to compact very easily and the fresh cement paste won't have any pores, but on the other hand the water/cement ratio will be too high, in the hardened cement paste the air takes up the place of the evaporated water and in consequence of that the compressive strength remains low.

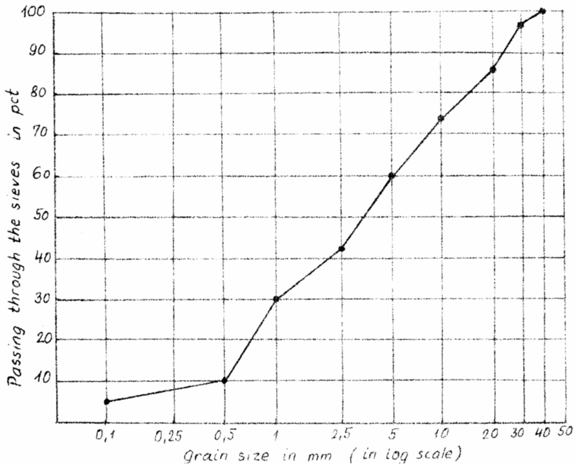


Fig. 3.: Grading curve

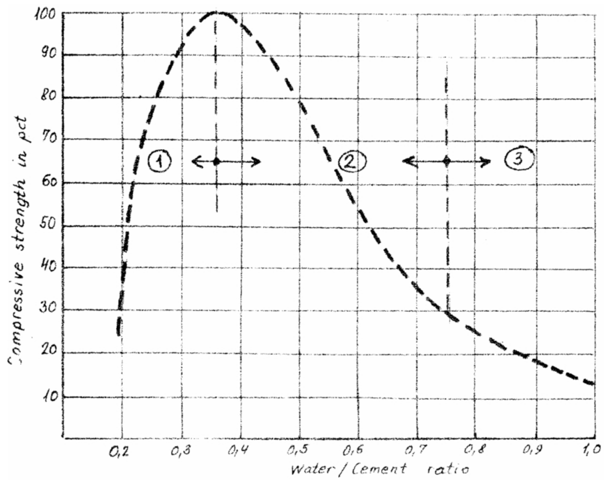


Fig. 4.: Relationship between water/cement ratio and compressive strength

d) It follows from the above mentioned rules, that we have to find the compromise: we have to make the concrete with a water quantity sufficient to compact the concrete making it dense and not more, than is just necessary.

In Figure 4. the relationship between the water/cement ratio and the compressive strength can be seen. We can distinguish three sections of this curve.

Section 1 characterizes the too low water content. In this section of water/cement ratio it is impossible to compact the concrete sufficiently by the given vibrator.

The section 2 characterizes the sufficient water content. To make a concrete construction without reinforcement and in a large mould we can apply the lower water/cement ratio (shortly: w/c ratio), i.e. 0,35-0,40. When concrete construction requires reinforcement and it will be compacted into a small, narrow mould, then we have to apply a higher w/c ratio, i.e. 0,5-0,6.

The section 3 characterizes too high water content. Inthis case concrete does not require compaction, it flows, but its compressive strength remains low.

To come back now to what were discussing, i.e. to the informations given by grading curves, we have to know – as compressive strength depends on water quantity – in what way the grading influences the water requirement.

In the first case we take grains without pores. Dense grains adsorb water on their surface (if grains had pores they would absorb water). The quantity of this adsorbed water depends on the surface of grains being in unit volume and on surface tension of water. By given water surface tension the coarse grains of 1 litre (e.g. 20-30 mm) adsorb less water than finer ones (e.g. 0-1 mm).

It can be seen in Figure 5 that besides the water adsorbed on the surface of coarse grains there are air bubbles too (Fig. 5/a) i.e. the space among grains I not filled completely with water. But in the case of fine grains (se Fig. 5/b) there are no air bubbles, i.e. the space among the grains is completely filled with water.

Figure 6. shows that the water quantity adsorbed on the surface of coarse grain will be multiplied when the coarse grain will be cut into slices.

It results from the above that the aggregate requires a lot of water if the grains are small and it requires a little water if the grains are large. So it would result from this that we must use an aggregate without fine grains.

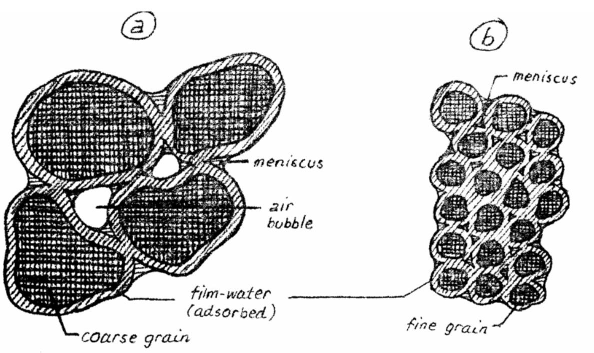


Fig. 5.: Adsorbed water on grain surfaces and air bubbles between the grains

On the other hand we have to take into consideration that only the well compacted concrete has sufficient compressive strength. As the workability of concrete depends on the mobility, cohesivity, water retention of the fresh mixture, we have to consider how these properties will b changed depending on the fine grain content. In this respect it is otherwise: the workability improves with growing fines content of aggregate.

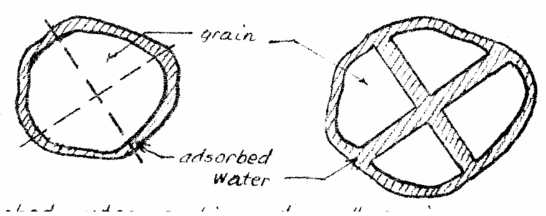


Fig. 6. Adsorbed water on big and small grains

So we have to find again a compromise: the fine content of the aggregate should be sufficient to the good workability, but should not be such a high, that the water requirement would increase exaggeratedly.

The whole concrete technology is composed of such compromises and its research is looking for the optimum.

We have to mention already now, that the lightweight aggregate concrete requires more fine content than the ordinary concrete. For information: in general a reinforcement lightweight concrete needs fine grains in the aggregate cca 30-60 pct, lightweight concrete for masonnary units needs cca 20-50 pct, insulating lightweight concrete needs cca 0-40 pct, depending on the maximum grain size. Namely the grading and in this the necessary fine content is influenced by the maximum grain size. Aggregate with a smaller maximum grain size (e.g. 10 mm) requires more fine content, than aggregate with a bigger maximum grain size (e.g. 40 mm). The maximum grain size is governed by the distance of reinforcement and by dimension of the framework. Big grains cannot hold in a narrow framework or do not get through interspaces of reinforcement.

It can be seen in Figure 7. the types of grading curves. Figure 7/a shows a continuous grading , which contains small quantity of fine grains. Figure 7/b shows also continuous grading, but its fine content is high. Figure 7/c shows a “gap-grading”, i.e. an aggregate without certain grain sizes. The different prescriptions (Standards, Code Practices etc.) give the limit-curves of gradings with different grain sizes. The grading of the used aggregate must be inside these limit-curves. In Figure 7/d can be seen aggregate with very high fine content; it is characterized by the quantity of very fine grains (under 0,1 mm).

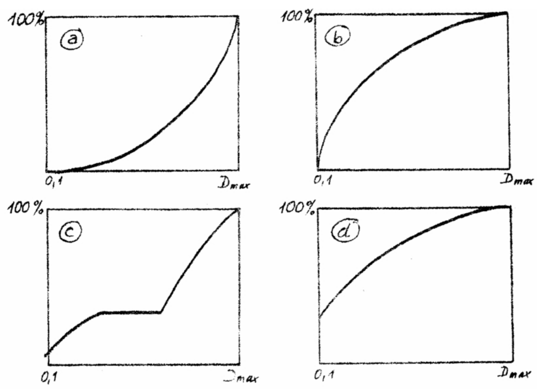


Fig. 7.: Different grading curve types

This very fine grains are in general harmful to the different properties of concrete, so they are seriously limited.

From the grading curve can be determined the so called *“Abrams fineness modulus”*. It gives the area which is determined by the curve, the ordinate and the upper vertical line (drawn at 100 pct.) as

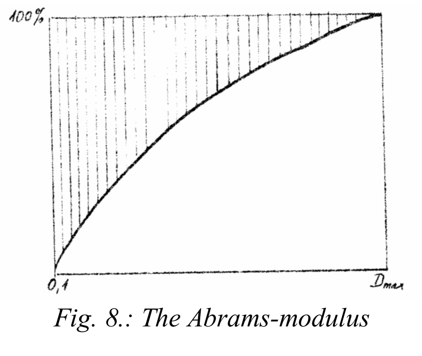


Fig. 8.: The Abrams-modulus

Figure 8. shows. To calculate the Abrams-modulus should be applied the Tyler-sieve series. These series contain the following sizes: 0,147; 0,295; 0,59; 1,8; 2,37; 4,75; 9,52; 19,05; 38,1 and 76,2 mm, i.e. this is a quadratic series (the following sieve sizes are always double of the preceding ones). We can screen the aggregate either on the metrical sieves (0,1; 0,5; 1; 2 mm etc.) or on the Tyler sieves, but we must calculate the Abrams-modulus in any case from he results on Tyler-sieves.

Lt's look at an example of the case, when we screened the aggregate on metrical sieves and calculated the Abrams-modulus on Tyler-sieves:

Sieve size in mm	0,1	0,25	0,5	1	2,5	5	10	20	30	40
Grains passed in g	150	400	900	1750	2700	3350	4050	4500	4900	5000
Through the sieves in %	3	8	19	35	54	67	81	90	98	100

As in Fig. 9. can be seen the grading curve was drawn from the results of screening on metrical sieves, then it was established the grain quantities in pct, which would have remained on the Tyler-sieves if we had screened the aggregate on these sieves. The area (the Abrams-modulus) can be calculated on the basis of approaching computation of area well-known from the geometry: we have to drop more perpendiculars are the vertical to the basic line equidistant from each other and to add the lengths of these perpendiculars. In our case the perpendiculars are the vertical lines (ordinates) drawn from the points of Tyler-sieves. To calculate the Abrams-modulus we divide the amount of residua by 100 – only for simplification. So the calculation is as follows

$$m = (95+89+77+61+48+34+20+11+1) : 100 = \\ = 4{,}36$$

Only for information: in the case of ordinary concrete the suitable aggregate has Abrams-modulus of 4-6 in general, in the case of lightweight aggregate concrete the Abrams-modulus of the suitable aggregates comes to 3-7. Besides in generally we have to look at the water absorption and desorption of lightweight aggregate. As in more cases the lightweight aggregates are lighter then water, the testing methods is as follows:

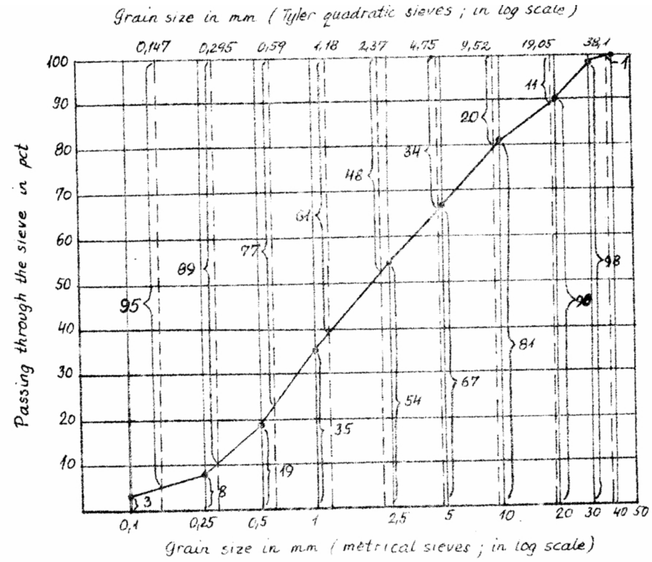


Fig. 9.: Calculation of Abrams-modulus

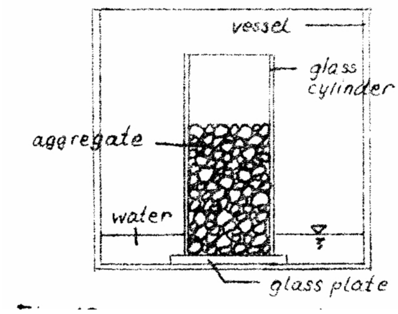


Fig. 10.: Water absorption testing

We place a glass-cylinder – opened at the bottom and on the top – on a glass-plate and weigh them together. We put into the glass-cylinder 1 litre of aggregate after weighing (generally with determined grading curve). We pour water into a vessel to height of 2 cm and place the glass-cylinder on glass-plate full of aggregate in the vessel (see Figure 10). We increase the water quantity in every hour with 2 cm until the water level reach the top of aggregate. After 24 hours we weighed the glass-cylinder on the glass-plate full with aggregate and calculate the water absorption in volume-percentage. The result is the water absorption in 24 hours *(A_{24})*.

Simple testing of desorption is as follows.

After water absorption testing the glass-cylinder on glass-plate full with aggregate will be put in a chamber of +20 °C temperature and 70 % air-humidity (or 65 %). Every day it shall be weighed until the weight changes. The results should be drawn according to Figure 11.

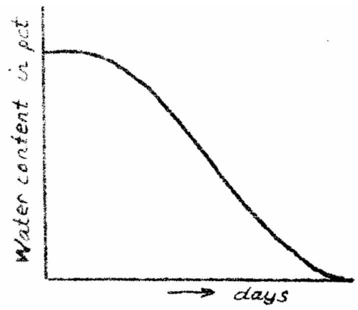


Fig. 11.: Course of water desorption

From these tests it can be evaluated – as we shall see later – the required water quantity to mixing and the drying speed of aggregate which is suitable to estimate the drying speed of concrete made from this aggregate.

We can influence the properties of concrete by additives, i.e. certain chemicals. If we make concrete at cold weather we can use accelerators, if we transport concrete long time we can mix to it retarders. To

make very light concrete we can use air-entrainer additives etc. The most important additive in the case of lightweight aggregate concrete is the air-entrainer. This chemical improves the workability, i.e. the mobility, the cohesivity, the water-retention and the compactibility of concrete as well as it can substitute the very fine aggregate (below 0,2 mm). The air-entrainers bring into beings very fine air-bubbles (∅ 30-80 μm) and the quantity of these air-bubbles not as high as 5 pct by volume, then the compressive strength is improved too. The air-bubbles are closed, they discontinue the capillary pores so the freezing-thawing resistance of concrete improves.

2.2. We have to prepare the basic materials in a satisfactory way

We have no trouble with preparation of cement and additives since we get them from factories. But it should be known that we have to protect the cement from every kind of humidity. Namely the cement begins to set, when it is touched by water or by humidity of air and it can be utilizable nevermore.

The way of preparation of aggregate results from the rules mentioned in Chapter 1.: we have to crush it – if it is necessary – and to screen for having suitable grading. There are some aggregates – perlite, certain types of scoria or pumice –, which do not require screening, they are utilizable in their natural state.

To choose the suitable crusher for crushing lightweight aggregates we have to know certain general rules about effect of crushing.

Frequency distribution curves of crushed materials are generally logarithmic-normal that is thex are inclined to the left and shifted – more or less – towards the axis of ordinates at the same time (see Figure 12., Part *a*).

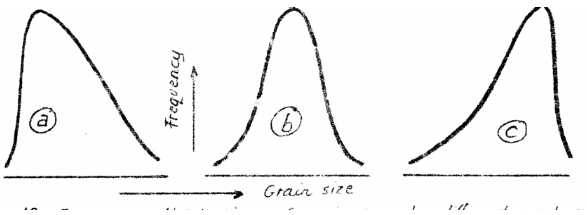


Fig. 12.: Frequency distributions of grain sizes by different crushers

But it is true for materials crushed by small-size crushers (mills and fine-grinding machines such as hammers) only. When crushed by any other type of crushers, grain-size distribution of materials will be – although somehow regular – but different from he figure 12/a. Rocks crushed by conic or jaw crushers have a Gauss-type frequency distribution (see Figure 12/b) while rollers (working at a low crushing rate) give rise to right-shifted frequency distribution. The latter is demonstrated by Figure 12/c.

As a practical conclusion of the above rules it can be stated, that:

a) hammers and gyratory crushers are to be preferred when at least 40 pct by weight of fine material (< 0,1 mm) is needed;
b) equally graned material can be produced by crushing on jaw- or conic-crushers;
c) high percentages of coarse material can be reached by using rollers (in this case the majority of the crushed material will be between D_{max} and $0,1 \times D_{max}$).

2.3. We have to weigh the necessary quantities of materials

In the technical literature we can read many articles about the effect of cement content. Many of them have misconclusions, because they do not take into consideration, that the concrete is combined material and its properties cannot be separated from its manufacturing, from the given technology process. First H.C. Erntroy and B.V. Shacklocks told data of design of high strength concrete mixes at the Symposium on *Mix Design and Quality Control* (1954, London), which characterized some typicalness of the real relationship between cement content and compressive strength, but their data had not significant influence.

Recently more investigations were carried out on this field and last two years in the Hungarian Institute for Building Science by direction of author. The following informations will be told on the basis of these investigations.

To determine the limit of optimum cement content of ordinary concrete we have to know the pore content (P) between grains of loose aggregate-cheap. If grains do not contain pores (such as in the case of quartz gravel and sand) the pore content between grains can be calculated from the specific density (D_s in kg/m^3) and the bulk density (B in kg/m^3) of aggregate:

$$P \text{ (litre/ 1 m}^3\text{ aggregate-heap)} = (D_s - B) / D_s \times 10$$

Aggregate of low fine content has pore-content of 200-260 litre/m^3, aggregate of high fine content has pore content of 260-340 litre/m^3, depending on maximum grain size. The task of the cement-paste is covering grains of aggregate and filling up the empty space between grains, i.e. these pores of 200-340 l/m^3. If the cement paste is just sufficient to fill up this space we call the concrete to be *"saturated concrete"* (i.e. saturated with cement-paste). If the cement-paste quantity is less than it is necessary to fill up this space, we call the concrete to be *"undersaturated concrete"*, and if the cement-paste more, the concrete is *"supersaturated"*. The different concrete structures can be seen in Figure 13.

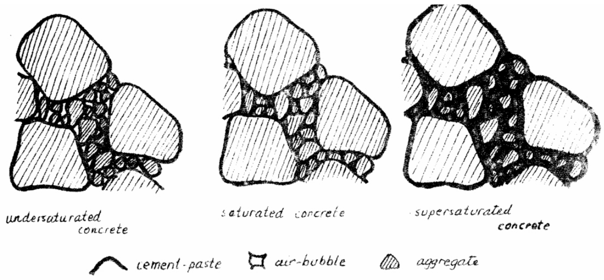


Fig. 13.: Different concrete structures

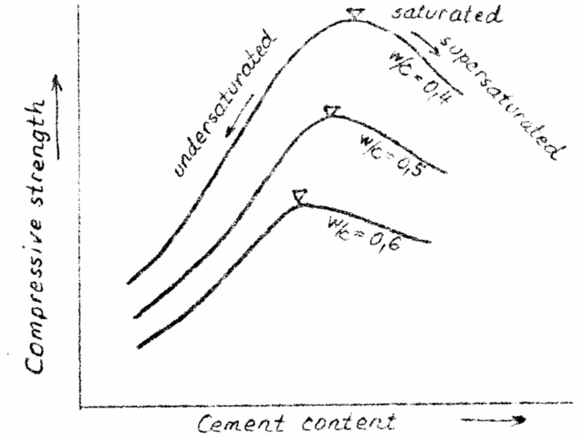


Fig. 14.: Relationship between cement content and compressive strength at different w/c ratio

On the basis of these structure-figures it can be easily explained the relationship between cement-content and compressive strength which can be seen in Figure 14.

We can state from these Figures, that at the same w/c ratio the saturated concrete has the maximum compressive strength and the cement content either increases or decreases compared to cement content of the saturated concrete, the compressive strength will be decreased.

Let's look at Figure 13. The undersaturated concrete has many air-bubbles, i.e. breaks of structure's continuity so it can be easily understood, that the compressive strength must be remained low.

As regards to the supersaturated concrete we have to take into consideration, that the concrete can be realized as a material composed of aggregate and cement-paste. The compressive strength of cement paste comes to 600 – 800 kp/cm^2 in customary cases, the compressive strength of aggregate (tested in cube or in cylinder) at ordinary concretes comes to generally 2000 – 3000 kp/cm^2, at lightweight concrete only to 1 – 150 kp/cm^2. It is obvious that in supersaturated normal concrete there are more weaker ingredients (i.e. cement paste). than in saturated concrete, so its strength must be lower.

We have to take notice of the density of ordinary concrete, because it is not limited. But in the case of lightweight aggregate concrete we have to take into consideration both density and compressive strength, so we have to investigate how these two properties are influenced by the cement content.

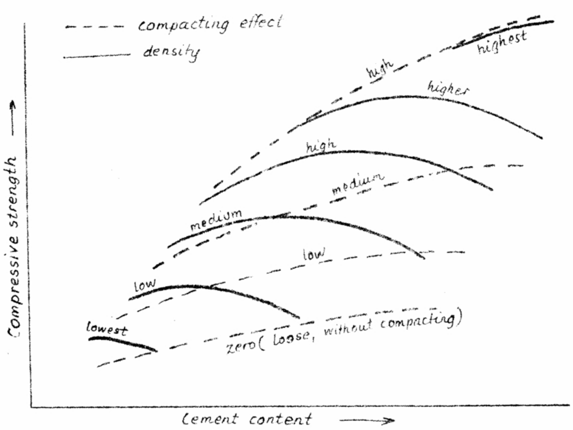


Figure 15.: Relationship among cement content, density, compressive strength and compacting

We wish in general to produce lightweight concrete with determined thermal conductivity (which is in close connection with density) and with determined load-bearing capacity(which is characterized by strength). Producing lightweight concrete we must take care of uniform and from above limited density, i.e. we must not make lightweight concrete with higher density, than that is prescribed. And we take care uniform and from below limited compressive strength, i.e. we must not make lightweight concrete with lower compressive strength, than that is prescribed.

These two requirements – low density and high strength – contradict each other. When we wish to produce high strength concrete, then we have to compact it vigorously, so the density will be alsp increased. Or to get high strength the cement mortar should be relatively high, so the density will be again increased. We have to find the compromise in the cement content and compacting method for manufacturing concrete with required properties. To this Figure 15. can give informations.

In the Figure it can be seen at the same density the compressive strength first increases, later decreases with increasing cement content. It can be seen too, that the higher is the density, the higher is the necessary cement content for obtaining the maximum compressive strength.

It can be read off Figure 15. the relationship among the cement content, the density, the compacting effect and the compressive strength. If we wish to produce e.g. lightweight concrete of medium density (e.g. 1600 kg/m^3) and of maximum strength obtainable at this medium density, we have to use medium compacting effect and medium cement content. Instead of these using either high compacting effect at the same medium cement content or high cement content at the same compacting effect both the compressive strength and the density increased, i.e. the concrete will not satisfy the requirements.

The valid relationships for every one of lightweight aggregates should be determined separately and these relationships give the most important informations of technology to be applied. Knowing the required compressive strength and density (D) of lightweight concrete, from these relationships it can be read the cement content (C) and it can be determined the necessary aggregate content (A) and water content (W):

$$A + W = D - C$$

The required water content was given from the results of aggregate water absorption testing in pct, so the concrete composition can be calculated as follows:

$$A + A \times W_{in\,pct} = D - C \quad \text{that is} \quad A \times (1 + W_{in\,pct}(= D - C \quad \text{so} \quad A = (D - C) : (1 + W_{in\,pct})$$

Example:

We have to make concrete of compressive strength 100 kp/cm^2 and of density 1500 kg/m^3 from scoria. The water absorption was 36 %. To these requirements the following data belong (from Figure): cement content $C = 240\ kg/m^3$ and medium compacting effect. The concrete composition?

$A = (D - C) : (1 + W_{in\,pct} = (1500 - 240) : (1\ ‘\ 0{,}36) = 1260 : 1{,}36 = 926\ kg/m^3$

$W = 1500 - (240 + 926) = 334\ l/m^3$ or $W = 926 \times 0{,}36 = 334\ l/m^3$

2.4. We have to mix the materials during necessary period

Mixing is used to transform the granulose materials into homogeneous mixture. Heap of dry materials (aggregate and cement) consists of different grains and air between grains. Mixing expels the air from the heap, i.e. it can be considered as a preliminary compacting. With mixing it can be obtained, that the water would cover grain surfaces of aggregate and cement, hereby it decreases internal frictions and given the necessary humidity to setting and hardening cement.

The mixing is effective if

- to carrying out it is needed relatively short time,
- ingredients of concrete are travelling n forced course,
- finishing the mixing only a few air remains in the mixture,
- ingredients (cement, aggregate grains, water and perhaps additives) are divided homogeneously in the mixture.

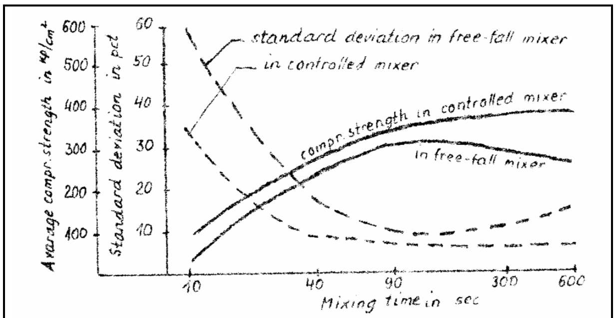


Figure 16.: Relationship among mixing time, compressive strength and standard deviation in different types of mixer

The necessary mixing time is determined by type of mixer. Investigations were carried out in Hungarian Institute for Building Sciences to establish the effect of mixing time on concrete properties. At these investigations not only the average compressive strength, but also the standard deviation were controlled. One part of the results can be seen in Fig. 16. According to these results , mixing of very short time gives very high standard deviation: it comes in controlled mixer to 36 pct, but in free fall mixer to 60 pct at mixing time of 10 sec. At this short time it can be obtained only a low compressive strength. Increasing mixing time the results are better, but in Free fall mixer we take also care of the too long mixing time.

Figure 16. gives relationship for one determined concrete composition. If the composition changes so does the standard deviation and average compressive strength too. Figure 16. concerns concrete of cement content 200 kg/m^3 and of medium sand (0-1 mm) content. If the quantity of fine ingredients decreases, the standard deviation will increase because of decreasing the fresh concrete cohesivity.

Mixing the lightweight aggregate concrete is very similar to that of the ordinary concrete. The literature suggests the pre-saturating the lightweight material. Its reason is, that though water absorption of lightweight aggregates is generally quick, but it continues more minutes. If we put into mixer dry aggregate and we begin mixing, the water absorption begins but it does not finish in the mixer. In this case the concrete can lose slowly

its workability and by the time we begin its compaction the concrete is already so dry, that we are not able to convert it into dense.

The pre-saturated aggregate contains such a quantity of water, which I just necessary, so in the mixer it is not needed to add more water.

2.5. We have to compact the concrete with suitable machine during satisfactory time

The importance of compaction can be seen in Chapter 2.3., in Figure 15. Et this Figure we have to look for compromise between concrete composition and compacting method. Here we add further comments. From the point of view of compaction the workability is the most important property of fresh concrete. The workability can be measured with many different methods, which can be divided into following groups:

methods of investigations

a) of fresh concrete deformation (Abrams-method);
b) of fresh concrete readiness for compacting (RILEM-Glanville method);
c) of penetration degree of some heavy, solid body into the fresh concrete (Graf-method);
d) of transformation degree of the fresh concrete (Powers-method).

The description of these methods can be found in technical literature. Here only one method will be discussed from the investigation procedures of fresh concrete readiness for compacting.

After mixing from fresh concrete should be taken out sample and measured its bulk density. For the investigation can be used the mould (cube or cylinder) in which the concrete specimens will be made. The fresh concrete should be poured into the mould loosely and the upper part of concrete should be planed (floated) without compacting. We weigh the loose concrete in the mould and calculate the bulk density of concrete (B_c):

$$B_c = [(W_{c+m} - W_m) : V] \times 1000 \text{ in kg/m}^3$$

where W_{c+m} = weight of mould and concrete in kg;
W_m = weight of empty mould in kg;
V = volume of mould in dm^3.

Then we make the specimens from the concrete with given compacting machine, measure the weight of fresh concrete and calculate the density (D_c) of it:

$$D_c = \{(W_c + m - W_m) : V\} \times 1000 \text{ in kg/m}^3$$

see marks above. The readiness for compacting (which gives the datum in pct):

$$R_c = \{(D_c - B_c) : B_c\} \times 100 \text{ in pct}$$

Concrete readiness for compacting expresses, that – after the given compacting – with how many percentage will be the fresh concrete heavier than without compacting.

In this Chapter examples of the different methods were given for investigating fresh concrete workability {see a) – d)}. The above outlined method is similar to the RILEM-Glanville's one, but at the RILEM-Glanville method is used a compacting machine to obtain a maximum density (i.e., theoretically ideal compacting machine really), to the here outlined method is used a practical compacting machine, which is generally used in situ. Nevertheless if a concrete has a good workability for one type of compacting machines, it does not indicate, that the same concrete has also a good workability using it in another type of compacting machines. This is why the here outlined method is preferred to the RILEM-Glanville one.

We have to discuss here the "satisfactory time". During compacting the air-bubbles are expelled from cement paste of concrete, the aggregate grains are going to come close to each other, the concrete density and so its compressive strength increase, If compacting time is short, the above written process is interrupted, concrete does not obtain the prescribed strength. If compacting time is long, it can be observed two faults. One of them is flowing out the cement paste, the other is the too high density. As it was told in Chapter 3., the required water content was given from results of aggregate water absorption. It should be completed here taking into consideration the compacting process.

Concrete readiness for compacting depends on grading of aggregate (in first place on its fine content), on the quantity of cement and the quantity of water. The relationship between fine content and water content was discussed in Chapter 2.1. so that between the cement and water content. Here the relationship will be treated between the compacting effect and water content.

Easy to realize: the easier are compacting the granulouse materials the lower is the frictional force between the grains. Together with the fine grains (cement and aggregate below 0,1 mm) the water gives possibility to decrease the friction. The higher is the water content, the lower is the frictional force, i.e. the less the compacting effect (capacity and time) is needed. It can be seen in Figure 17., when at the same aggregate:cement mixture the water quantity is increasing, then by unchanged compacting effect the density will be increasing too, till the optimum point, but using more water the density begins to decrease.

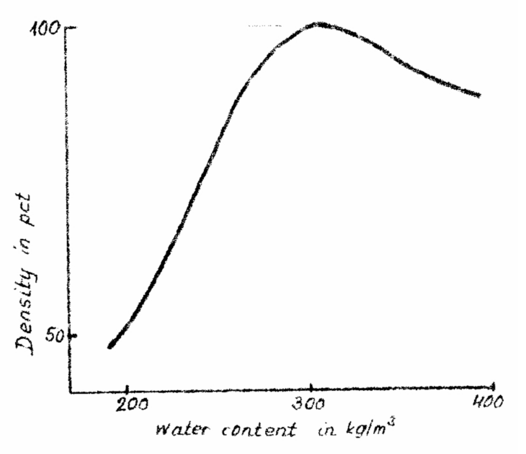


Figure 17.: Relationship between water content and density by unchanged compacting effect

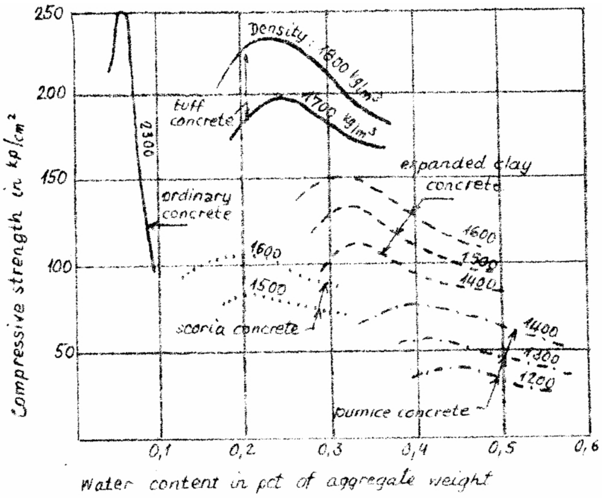


Figure 18.: Relationship between water content as well as density and compressive strength

The relationship between water content and compressive strength can be seen in Figure 18. for different aggregate. For the sake of comparability in the Figure it can be found the ordinary concrete too. From Figure 18. it can be stated, how the water content influence the density and compressive strength at different lightweight aggregate concretes. Once again it should be emphasized: to determine the most suitable composition of concrete and circumstances of its production is looking for compromise.

2.6. We have to cure the compacted concrete

To setting and hardening cement water is required. In the first period the water added to cement and aggregate at mixing is satisfying, but if the water evaporated, setting and hardening cement would be interrupted. Therefore we have to hinter drying so we keep the wet condition by watering. Its length of time depends on the air humidity, sunshine, wind etc. The prescription require in generally curing of 7 days.

Making concrete specimens in laboratory and investigating their compressive strength curing is also required. We have to know that the water content (humidity) of concrete influences their strength in two ways:

a) some types of aggregates (principally materials with clay-content) are smoother wet than dry, so concretes made with these aggregates are weaker wet than dry.

b) Investigating concrete specimens testing results depend on surface humidity of concrete, because friction comes into being between the pressing plate and the concrete surface. The wetter is the surface the lower is tge tested compressive strength even if the real compressive strength were equal.

So we have to take care of equal humidity of specimens so the curing conditions should be equal, Curing of lightweight aggregate concrete is generally: 7 days at wet condition (> 98 % air humidity, +20 °C), 21 days at dry conditions (65 – 70 % air humidity, +20 °C).

3. INVESTIGATION PROGRAM OF ICELANDIC ÉIGHTWEIGHT VOLCANIC MATERIALS

Intention of these informations in Chapter 2.1. – 2.6. was to establish, to make evident the program of investigations of Icelandic lightweight volcanic materials presumably suitable to making concretes. It seemed necessary to summarize the most important informations because the expert of UNIDO stays in Iceland only to the end of October so the finishing the investigations and evaluating their results are charge of Icelandic counterpart.

3.1. Purpose of investigations

The purpose of these investigations to compare the properties of lightweight volcanic materials that can be found in district of Reykjavík for selection and on the basis of results to chose the most suitable material for building industry. The previous estimations established that these materials should be primarily considered for manufacturing concrete so the investigations shall be concrete technological ones. During these investigations should be determined the using fields of materials (in load-bearing constructions, in masonry units, in heat-insulating products) as well as main parameters of technology to be applied to production.

Moreover the purpose of these investigations to furnish data for export-oriented marketing activity on the field of lightweight volcanic materials.

3.2 Method of investigations

The methods applied to investigations of aggregate should be based upon ASTM asnd Hungarian Standards. These methods are written in Chapter 2. of these paper.

The methods applied to investigations of concrete technology should be based upon system developed by author.

At investigations it should be taken into consideration the equipment of Building Research Institute at Keldnaholt (Iceland) so the instruments attainable for testing can modify the practical performance but without any modification of their theoretical basis.

3.21. Comparative testing deposits

For comparative investigation it should be taken out sample from different scoria and pumice deposits: three deposits in district of Hekla and Katla of pumice and six deposits near to Rejkjavík of scoria. These deposits have different materials in colour (e.g. red and black) and in grain size, so it should be taken out more samples of different colour or grain size from the same deposit. Investigations are to be carried out:

a) testing bulk density of materials on grain size of 4-19,5 mm;
b) testing self strength of materials on grain size of 4-19,5 mm;
c) testing grain distribution of materials;
d) testing water absorption.

The results should be processed according the following Tables:

Type of the material	Deposit	Estimated quantity in million m^3	Distance from Rejkjavík harbour	Quality according to survey

Testing self strength

Mark of samples	Bulk density in kg/m^3	Weight of sample in kg	Force in kp at impressure		Self strength at 2,54 cm in kp/cm^2		Self strength at 5,08 cm in kp/cm^2	
			2,54 cm	5,08 cm	single	average	single	average

Surface of cylinder: 19,6 cm^2 Volume of cylinder: 236 cm^3

Testing bulk density

Mark of sample	Weight of sample in kg	Bulk density in kg/m^3	
		single	Average

Volume of cylinder: 2130 cm^3

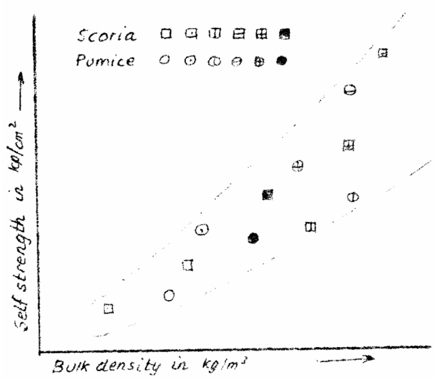
Testing grain distribution

Mark of sample	Sieve size British Standard	Grain size in mm	Residuum	
			g	%

Tested quantity: 5000 g

Testing water absorption

Mark of sample	Quantity of dry material		Water absorption after …. hours / in …							
	in g	in litre	24		48		72		98	
			g	pct.Vol.	g	pct.Vol.	g	pct.Vol.	g	pct.Vol.



Fig, 19.: Sketch for testing evaluation

Results of testing grain distribution should be drawn in Figure (grading curve) as well as results of testing bulk density should be plotted against results of testing self strength. In Figure 19. can be seen the sketch of this relationship.

This Figure gives the basis of evaluation, because it is advisable to choose materials of low density and simultaneously of high compressive strength. Of course for evaluating data of investigations it should be taken into consideration the estimated quantity and the distance of deposit from Rejkjavík harbour too.

According to this evaluation it should be taken out samples of big quantity (about 5 m3) from three or four deposits for testing concrete technology and properties of concretes.

3.22. Technological investigations

The technological investigations should be carried out with big samples of about 5 m^3. We wish to determine by these investigations the technological behaviour materials as well as the properties of concretes made with them.

a) Preparatory works

After drying the aggregates should be screened on following sieves: 1,5 in (38,1 mm), 1 in (25,4 mm), No.4 (4,76 mm) and No.16 (1,19 mm). The residuum on 1,5 in sieve should be crushed to max. grain size 38,1 mm and screened on above sieves again (1,5 in, 1 in, No.4 and N.16). After screening the following fractions are at our disposal:

0 – 1,19 mm
1,19 – 4,76 mm
4,78 – 25.40 mm
25,40 – 38,10 mm

The fraction of 4,76 – 25,4 mm should be screened (from slight quantity of it) on sieves 9,6 and 19,5 mm to testing self strength and bulk density. To both testing we use aggregate composition of 50 pct 4,76 – 9,6 mm and 50 pct 9,6 – 19,5 mm. Furthermore we investigate the grain distribution of 0 – 1,19 mm fraction and the water absorption of each fraction. The absorbed water quantity should be measured after 30 min. furthermore 1, 24 48 and 96 hours. The results should be determined in Tables according to Chapter 3.21.

b) General investigations

We put together from fractions aggregate mixture of following grain distribution:

0 – 1,19 mm	= 35 pct by weight
1,19 – 4,76 mm	= 30 pct by weight
4,76 – 25,4 mm	= 35 pct by weight

We make concretes of the following composition from this aggregate:

Type I cement : aggregate : water by weight = 1 : 2 : (0,8)
Type II cement : aggregate : water by weight = 1 : 3 : (1,1)
Type III cement : aggregate : water by weight = 1 : 4 : (1.4)
Type IV cement : aggregate : water by weight = 1 : 5 : (1,7)

Explication:

The water content can be calculated on water required by cement and aggregate. The water by cement comes up to 20 pct of cement weight (0,2 x cement). The water required by aggregate can be calculated from data of water absorption investigations (see above). The data in parantheses were calculated supposing water required by aggregate of 30 pct and water required by cement of 20 pct so the total water (in parantheses) = 0,2 x C + 0,3 x A. The exact water quantity will be determined separating for each material after testing aggregate water absorption.

The materials of above quantity should be mixed in controlled mixer during 90 sec. First we mix cement and aggregate during 30 sec, then we add water and continue mixing further 60 sec.

From eh mixture we make specimens. The first three specimens will be made without compacting. We pour the mixture into the cylinder and clear down its top with metal ruler without compacting too. We measured the weight of empty cylinder (W_{ce} in kg) and cylinder with concrete (W_{cc} in kg) and knowing the cylinder volume (V_c in dm^3) the fresh concrete density (= the bulk density of fresh concrete) can be calculated:

$$D_f = \{(W_{cc} - W_{ce}) : V_c\} \times 1000 \text{ in kg/m}^3$$

The second three specimens will be made with strongest compacting which can be applied altogether. After compacting we measure their weight and calculate the density.

Between these two densities (lowest and highest) we choose two intermediate densities, weigh the appropriated concrete quantity (W_c) and compact into cylinder. The appropriated concrete quantity can calculated from chosen density (D_f) and cylinder volume (V_c):

$$W_c = (D_f : 1000) \times V_c \quad \text{in kg}$$

Example:

The average density of the first three specimens was 1080 kg/m^3, that of the second three specimens was 1630 kg/m^3. The two intermediate densities should be: 1250 kg/m^3 and 1450 kg/m^3. If we use cylinder of 6x12 in (its volume is 5,5 litres) we have to measure the following quantities:

for concrete of density of 1250 kg/m^3 = 6,9 kg to each cylinder
for concrete of density of 1450 kg/m^3 = 8,0 kg to each cylinder

Explication:

The most important relationship of lightweight aggregate concrete could be seen in Fig.15. This relationship can be constructed in the following way:

We make concretes of different composition (see Type I – IV concretes). We compact each composition in different ways and in consequence of it the concretes will have different densities and different compressive strength.

If we make specimens with four concrete compositions and we compact each composition in four different way, we get 16 data which Figure 15. can be constructed with. The construction of this Figure should be explained by example.

The results of investigations should be as follows:

Mix proportion by weight cement:aggregate: water	Properties	Results of			
		first	third	fourth	Second
		Compacting			
1 : 5 : 1,7	Density of fresh concrete in kg/m^3	1080	1250	145	1630
	Cement content in kg/m^3	140	161	188	212
	Compressive strength in kp/cm^2	13	24	58	98
1 : 4 : 1,4	Density of fresh concrete in kg/m^3	1120	1300	1500	1700
	Cement content in kg/m^3	175	203	234	265
1 : 4 : 1,4	Compressive strength in kp/cm^2	22	40	75	148
1 : 3 : 1,1	Density of fresh concrete in kg/m^3	1150	1300	1500	1760
	Cement content in kg/m^3	226	255	295	3456
	Compressive strength in kp/cm^2	26	48	83	180
1 : 2 : 0,8	Density of fresh concrete in kg/m^3	1200	1350	1550	1810
	Cement content in kg/m^3	316	356	408	476
	Compressive strength in kp/cm^2	29	50	98	220

From these data figure should be constructed where the cement content is plotted against the density of fresh concrete. This figure can be seen in part A of Figure 20.

Likewise other figure should be constructed, where the cement content is plotted against the compressive strength (see part B of Figure 20. continuous lines).

From these two Figures can be constructed the Figure according to Fig. 15. The course of construction is as follows:

In Figure 20 part A we look for points of intersection of one density (e.g. 1200 kg/m^3) and the lines marked the relationship between cement content and density. From these points we erect perpendiculars and lines marked relationship between cement content and compressive strength should be connected (see Figure 20 part B dotted lines).

We continue the construction to draw lines for further densities (e.g. 1300 kg/m^3, 1400 kg/m^3 etc. see part B of Fig. 20.). If the investigations were performed carefully, the relationship can be easily constructed. Even the most accurate investigations can give some differences in results, consequently it cannot be avoided certain rectifications. To do it well we have to know, that the relation between cement content and density is always straight-lined and the relation between cement content and compressive strength is always curve of the second (or third) order.

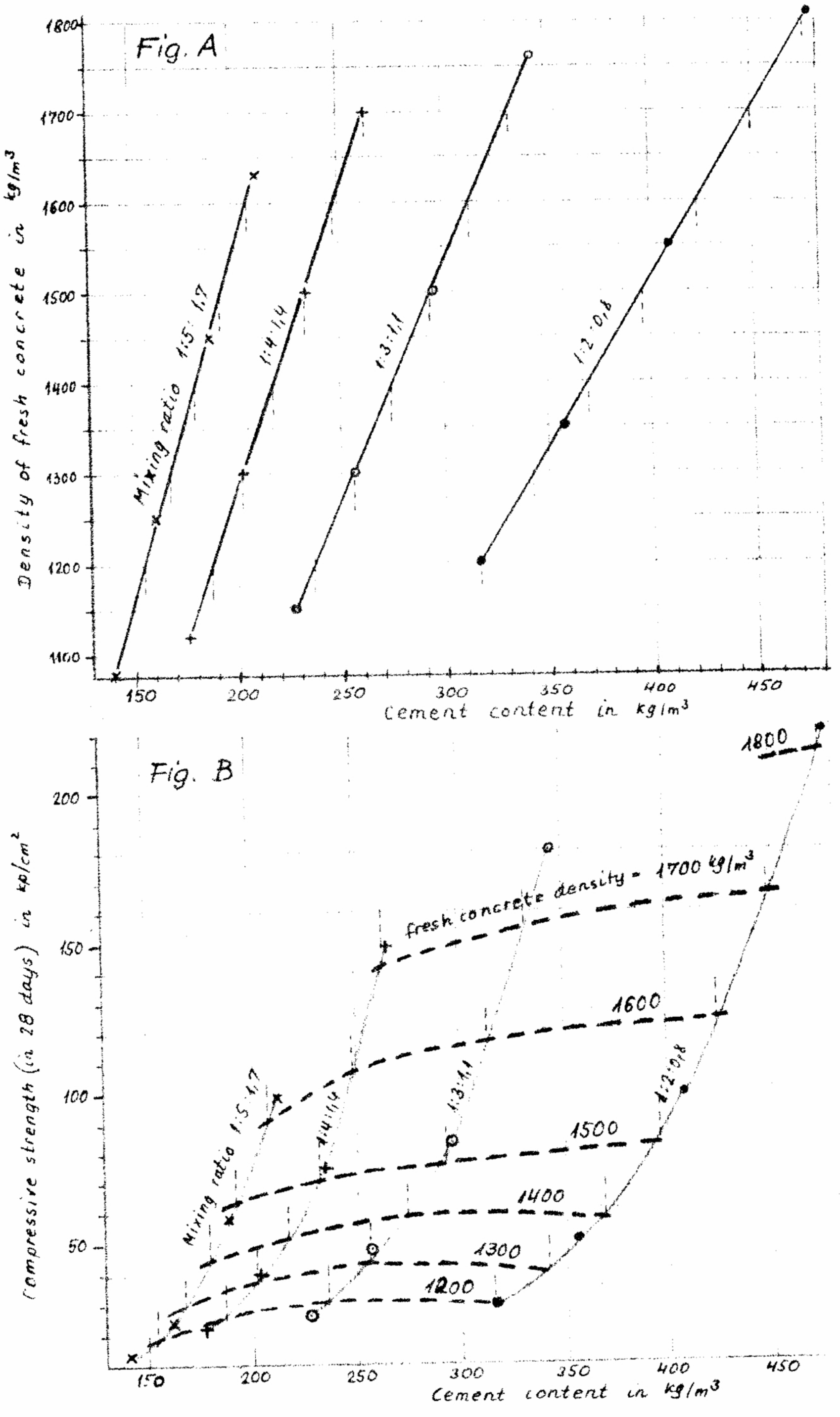


Figure 20. : Construction of relationship among cement content, density and compressive strength

c) Detailed technological investigations

In the course of detailed technological investigations effect of following factors should be tested:

I effect of aggregate fine content
II effect of water content
III effect of air-entrainer additives

I Effect of aggregate fine content

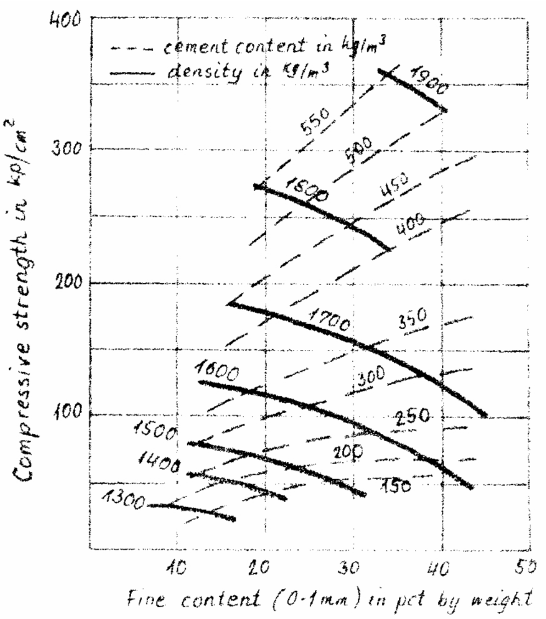


Figure 21.: Relationship among fine content, cement content, density and compressive strength

Aggregate:	*blast furnace slag*
Crumbling factor of Hummel:	*0,83*
Bulk dnsity :	*760 kg/m³*

General information can be seen in Figure 21. where data of research carried out in the Hungarian Institute for Building Sciences are shown.

The effect of aggregate fine content can be investigated with different concrete composition and with single compacting method (highest compacting effect). To the tests we compound the following grading curves:

Fractions	*0-1,19*	*1,19-4,76 mm*	*4,76-25,4*
Composition IA	*10*	*30*	*60*
IB	*20*	*30*	*50*
IC	*35*	*30*	*35*
ID	*50*	*30*	*20*

The compositions of concrete by weight should be as follows:

Type I	*cement:aggregate:water*	*= 1 : 2 : (0,8)*
Type 11		*= 1 : 3 : (1,1)*
Type III		*= 1 : 4 : (1,4)*
Type IV		*= 1 : 5 : (1,7)*
Type V		*= 1 : 6 : (2,0)*
Type VI		*= 1 : 7 : (2,3)*

As specimens with the IC aggregate (fine content: 35 pct) and Type I-IV compositions were made in the course of previous investigations (Chapter 3.22/b) we only have to make concretes now with mix proportions according to the following Table:

Fine content (0-1,9 mm)		*10*	*20*	*35*	*50 pct*
Mix proportion	*1:7:(2,3)*	+	+	+	+
	1:6:(2,0)	-	-	+	-
	1:5:(1,7)	+	+	-	+
	1:4:(1,4)	-	-	-	-
	1:3:(1,1)	+	+	-	+
	1:2:(0,8)	+	+	-	+

After these investigations there are at our disposal every result of concretes with mix proportion 1:7:2,3); 1:5:(1,7); 1:3:(1,1) and 1:2:(0,8) as well as every result of concretes with fine content of 35 pct. For construction of relationship (according to Figure 21.)these results are satisfying.

Example

The data of investigations can be seen in the next Table:

Mixing ratio	Properties	Fine content in pct			
		10	20	35	50
1:7:2,3	Density of fresh concrete in kg/m³	1200	1350	1460	1540
	Cement content in kg/m³	116	130	142	148
	Compressive strength in kp/cm²	1	2	12	24
1:6:2,0	Density of fresh concrete in kg/m³			1560	
	Cement content in kg/m³			174	
	Compressive strength in kp/cm²			48	

continuation in the next page

Mixing ratio	Properties	Fine content in pct			
		10	20	35	50
1:5:1,7	Density of fresh concrete in kg/m^3	1510	1550	1630	1670
	Cement content in kg/m^3	196	1201	212	216
	Compressive strength in kp/cm^2	41	54	98	110
1:4:1,4	Density of fresh concrete in kg/m^3			1700	
	Cement content in kg/m^3			265	
	Compressive strength in kp/cm^2			148	
1:3:1,1	Density of fresh concrete in kg/m^3	1610	1660	1760	1850
	Cement content in kg/m^3	316	325	345	362
	Compressive strength in kp/cm^2	105	140	180	210
1:2:0,8	Density of fresh concrete in kg/m^3	1660	1730	1810	1890
	Cement content in kg/m^3	436	455	476	496
	Compressive strength in kp/cm^2	145	190	220	250

For construction of the relationship among fine content, density, cement content and compressive strength Fig.22.gives information. On this Figure points show the data on this Table. The values of density are written on right side of points, values of cement content on the left. The curves are compensating ones of the points.

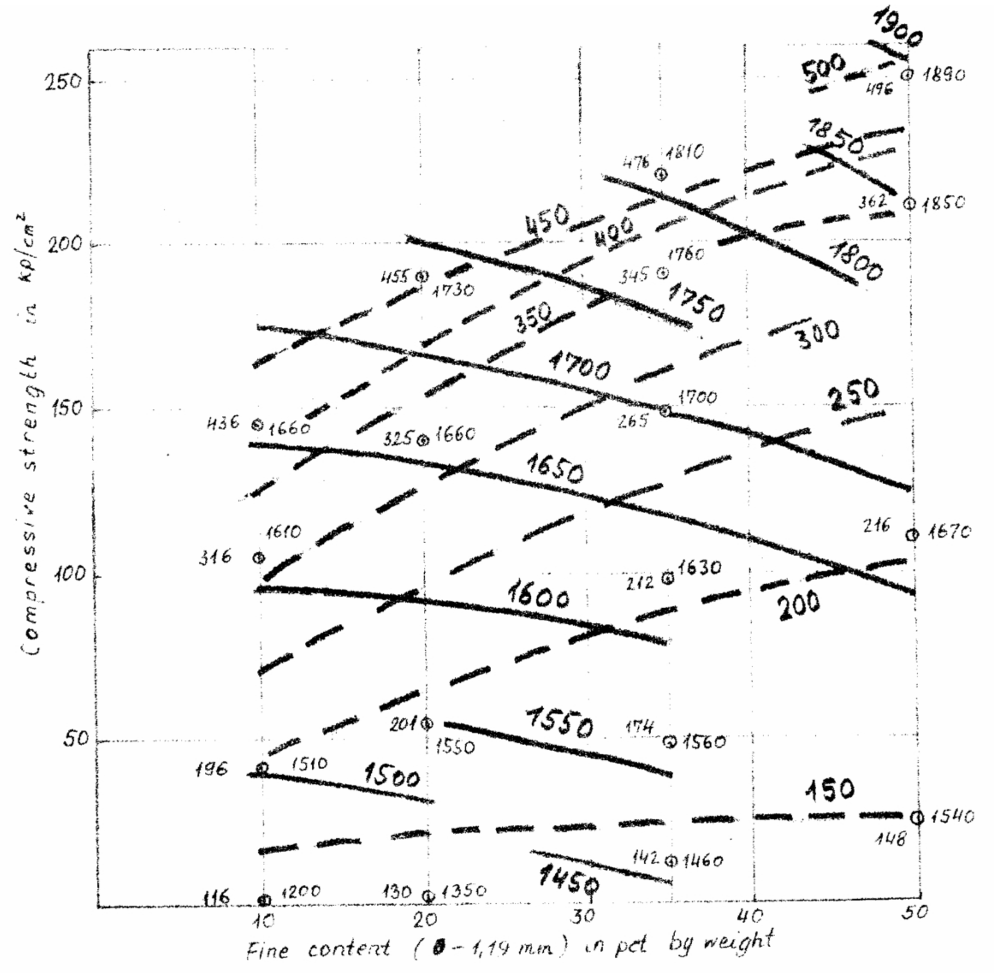


Figure 22. Construction of relationship according to Fig. 21. on the basis of example

II Effect of water content

General information can be seen in Figure 18. The effect of water content should be investigated with two concrete composition and with single compacting method. The fine content will be 35 pct (0-1,19 mm). The mixing ratios: 1:5 and 1:3 cemet:aggregate. The water quantity shall be 20 pct of cement weight and varying pct of water: 0,2 . A; 0,25 . A; 0,28 . A; 0,30 . A; 0,32 . A; 0,38 . A and 0,40 . A. The water quantity of 0,2.C + 0,3.A was investigated in the course of general investigation (see on page 19), therefore now it is not needed to repeat it.

Mixture are to be made:

cement : aggregate : water =	1 : 5 : 1,20	1 : 3 : 0,80
	1 : 5 : 1,45	1 : 3 : 0,95
	1 : 5 : 1,60	1 : 3 : 1,04
	1 : 5 : 1,80	1 : 3 : 1,16
	1 : 5 : 1,95	1 : 3 : 1,25
	1 : 5 : 2,20	1 : 3 : 1,40

Remark: The above ratios can be applied only in the case, when the water absorption of aggregate was 30 pct by weight. When the water absorption changes, the ratio must be changed according to the meaning.

To the making specimens the greatest compacting effect should be applied but we have to take into consideration, that the applicable effect depends on water content. If the water quantity is very small (the concrete s very dry) we can compact the concrete very strongly (e.g. long time vibration under pressure), but concrete of very high water content can only take a short time vibration (by longer time vibration one part of cement paste would be leaking from the concrete. The vibration will last to the moment, when the water appears on the surface of specimen, the concrete will liquify.

Though these investigations do not give possibility to drawing relationship according to the Figure18. – drawing this relationship would need much more specimens – but they are suitable for getting general information about the effect of water content.

Example:

Results of investigations can be seen in the following Table:

Mixing ratio: cement:aggregate:water	Water content in pct of aggregate weight	Density	Cement content	Water content	Compressive strength in kp/cm^2
		of fresh concrete in kg/m^3			
1 : 5 : 1,20	20	1540	214	256	15
1 : 5 : 1,45	25	1600	215	311	56
1 : 5 : 1,60	28	1620	214	341	83
1 : 5 : 1,70*	30*	1630*	211	359	98*
1 : 5 : 1,80	32	1640	210	378	108
1 : 5 : 1,95	35	1650	206	403	110
1 : 5 : 2,20	40	1650	201	443	90
1 : 3 : 0,80	20	1610	335	269	35
1 : 3 : 0,95	25	1680	340	323	114
1 : 3 : 1,04	28	1730	342	356	166
1 : 3 : 1,10*	30*	1760*	349	383	180*
1 : 3 : 1,15	32	1780	345	400	190
1 : 3 : 1.25	35	1800	344	429	195
1 : 3 : 1,40	40	1800	334	467	182

* from investigations in Chapter 1.22/b

The relationship constructed by the above date can be seen in Figure 23. Close to points of investigations the densities of fresh concrete are written. It is to be noted, that density of dry concrete is more important property, than that of fresh one. These data can be calculated on the basis of concrete composition and fresh concrete density in the following way:

Cement binds chemically water about 20 pct of own weight, the other part of the water content evaporates in the course of hardening. If the concrete is during the hardening (after 7 days curing) in dry climate, its evaporation ends generally in 28 days. The hardened dry concrete contains cement, aggregate as well as chemically bound water = 0,2 . C. Reduction in concrete weight comes to $X = W - 0,2.C$ where W means the water content of fresh concrete. Calculating this reduction in weight the dry concrete can be seen in the following Table.

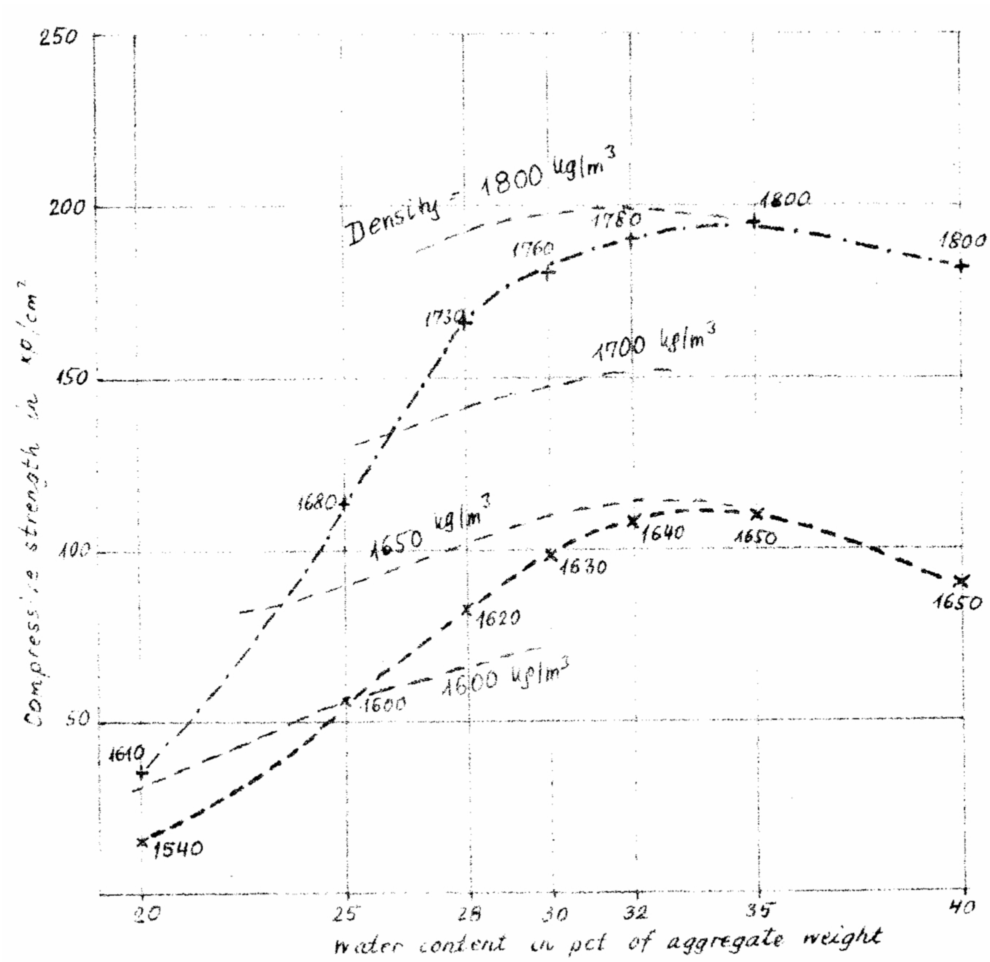


Figure 23.: Relationship between water content and compressive strength

Mixing ratio cement:aggre-gate:water	Water content in pct of aggre-gate weight	Water content of fresh con-crete in l/m³	Lose of water X = W – 0,2.C In l/m³	Density of fresh	Density of Dry
				Concrete in kg/m³	
1 : 5 : 1,20	20	256	213	1540	1327
1 : 5 : 1,45	25	311	268	1600	1332
1 : 5 : 1,60	28	341	298	1620	1322
1 : 5 : 1,70	30	359	317	1630	1313
1 : 5 : 1,80	32	378	336	1640	1304
1 : 5 : 1,95	35	403	362	1650	1288
1 : 5 : 2,20	40	443	403	1650	1247
1 : 3 : 0,80	20	269	202	1610	1408
1 : 3 : 0,95	25	323	256	1680	1425
1 : 3 : 1,04	28	356	288	1730	1442
1 : 3 : 1,10	30	383	313	1760	1447
1 : 3 : 1,16	32	400	331	1780	1449
1 : 3 : 1,25	35	429	360	1800	1440
1 : 3 : 1.40	40	467	400	1800	1400

It can be seen from this Table, that increasing the water content the fresh concrete density increases continually but the dry concrete density increases only initially then decreases. In consequence of this fact it can be stated, that the water content does not influence considerably the density of dry concrete, but through the improvement of workability the high water content is advantageous for the compressive strength. So it advisable to add rather more water than less.

III Effect of air-entrainer additives

As it was told at the end of Chapter 2.1. the most important additive in the case of lightweight aggregate concrete is the air-entrainer. This chemical improves the workability, consequently the investigations of effect of this additive should be concerned testing the readiness of compacting. It should be made mixture of different composition with and without additive and fter having measured their bulk density it should be compacted with highest effect.

As the air-entrainer makes decreasing water quantity possible without charge of original workability (i.e. workability of concrete made without additive) it should be investigated the permissible degree of decreasing water and effect of this on compressive strength.

To investigate each possible variation it would be needed many specimens. To reduce the number of specimens the following mixtures are to be made and investigated:

Cement : Aggregate : Water : Additive proportion by weight				
Original mixture*	With additive and unchanged water quantity		With additive and changed water quantity	
1 : 7 : 2,3 : 0	1 : 7 : 2,3 : 0,01	1 : 7 : 2,3 : 0,02	1 : 7 : 2,16 : 0,01	1 : 7 : 1,95 : 0,01
1 : 6 : 2,0 : 0	1 : 6 : 2,0 : 0,01			
1 : 5 : 1,7 : 0	1 : 5 : 1,7 : 0,01	1 : 5 : 1,7 : 0,02	1 : 5 : 1,60 : 0,01	1 : 5 : 1,46 : 0,01
1 : 4 : 1,4 : 0	1 : 4 : 1,4 : 0,01			
1 : 3 : 1,1 : 0	1 : 3 : 1,1 : 0,01	1 : 3 : 1,1 : 0,02	1 : 3 : 1,04 : 0,01	1 : 3 : 0,95 : 0,01
1 : 2 : 0,8 : 0	1 : 2 : 0,8 : 0,01			

* Data from investigations in Chapter 3.22/b and 3.22/cI

In the course of the investigations it should be measured the bulk density of the mixture, the density of fresh concrete and the compressive strength in 28 day of concrete.

In Figure 24. sketch can be seen for processing data of these investigations.

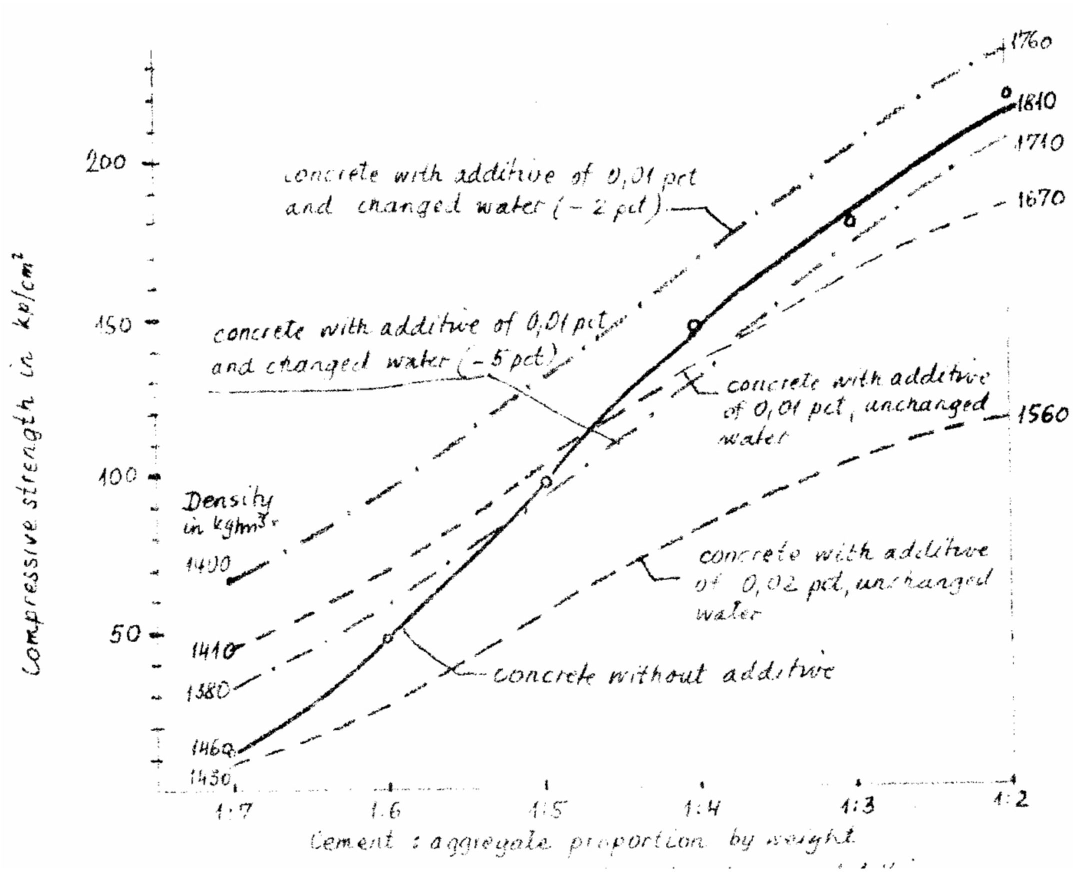


Figure 24.: Relationship-sketch for effect of air-entrainer additive

3.23. <u>Evaluation of results of technological investigations</u>

According to the RILEM Recommendation lightweight aggregate concrete can be classified in the following groups:

Designation of concrete	*Density* in kg/m^3*	*Compressive strength** in kp/cm*	*Thermal conductivity*** in $kcal/mh^oC$*
Thermal insulating concrete	≤ 800	≥ 1	≤ 0,25
Intermediate concrete	≤ 1600	≥ 35	≤ 0,65
Load-bearing concrete	≤ 1900	≥ 140	--

* measured after drying
** measured in cube
*** measured with consolidated humidity

To classify the investigated lightweight aggregate concrete it should be determined the obtainable upper and under limits of density and compressive strength. It should be taken into consideration the technical and economic possibilities, i.e. cement content should not be higher than cca 450 kg/m^3 and the compacting effect should not be very low.

On the basis of under and upper limits it can be established the category the given concrete can be included in. The category will specify investigations to be carried out.

The investigations can be found in following Table:

Designation of concrete	*A*	*B*	*C*	*D*	*E*	*F*	*G*
Thermal insulating concrete	+		+		+	+	+
Intermediate concrete	+	+	+	+	+	+	+
Load-bearing concrete	+	+	+	+		+	+

A Bending strength *B* Young-modulus *C* Shrinkage *D* Freezing-thawing resistance
E Thermal conductivity *F* Water absorption *G* Speed of drying

The testing methods are regularized by Standards so they wont't discussed here. Numner of specimens shall fulfil terms of Standards.

a) Bending strength

On the basis of investigations according to Chapter 3.22/b seven compositions should be chosen from strongly or medium compacted mixtures of about following compressive strengths:

Thermal insulating concrete	5	10	35	-	-	-	-
Intermediate concrete	-	-	-	50	100	-	-
Load-bearing concrete	-	-	-	-	-	200	300

The results shall be drawn according to Figure 25.

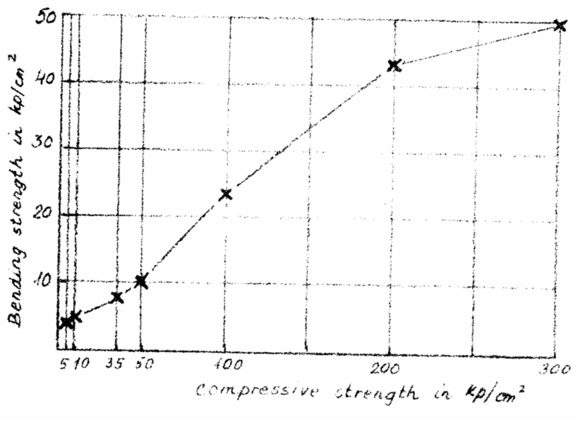


Figure 25. Relationship between compressive strength and bending strength

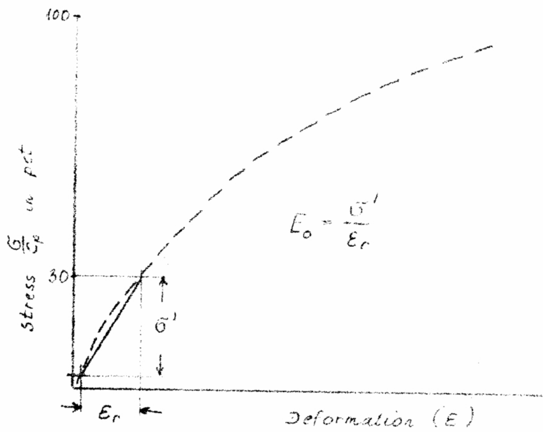


Figure 26.: Young modulus

b) Young-modulus (modulus of elasticity)

Young-modulus is the directional tangent of curve-origin drawn for relationship between deformation and stress. Testing Young-modulus the specimen is loaded with a relatively small weight (e.g. 500 kg) and origin curve concerns to this point (see Figure 26.). Young-modulus of ordinary concrete depends only on its compressive strength. Different Standards give formulas for relationship between compressive strength and Young-modulus (E_o), e.g. formula of Roš:

$E_o = 600000 \times \{C_p : (C_p + 150)\}$ where C_p = compressive strength measured in prism in kp/cm^2

Young-modulus of lightweight concrete depends on compressive strength and density. Schäfler worked out the following formula: $E_o = 6000 \times \sqrt{\rho \times C}$

where ρ = density of concrete in kg/dm^3
C = compressive strength measured in cube in kp/cm^2

It must be called attention: the multiplying factor (6000) cannot be constant, it depends on type of aggregate, furthermore other authors (e.g.. Paw) does not give linear relation for density but he calculates with $\rho^{2/3}$.

To investigate Young-modulus specimens of about following compressive strength should be made:

Intermediate concrete	50	100	-	-
Load-bearing concrete	-	-	200	300

Since Young-modulus is to be investigated in prism, we have to investigate the compressive strength in prism and measure the Young-modulus at stress-level of 30 pct of prism's compressive strength.

c) Shrinkage

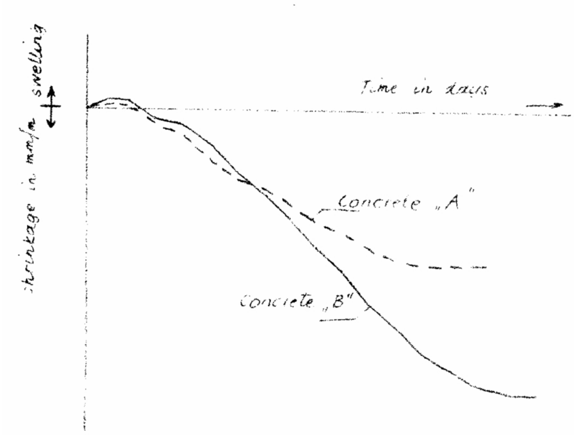


Figure 27.: Shrinkage

Drying concrete shrinks and absorbing water it swells. If concrete is of great shrinkage it is inclined to cracking. Shrinkage should be tested on concretes according to Chapter 3.23/a..

Time change of shrinkage should be drawn according to Figure 27.

Concrete shrinkage is reversible process, therefore quick testing can be carried out in the following way:

The concrete will be placed under water. After saturation its length will be measured with a precision measuring instrument (required accuracy is 1/100 mm). Then it will be put into drier and after drying its length will be measured. Length after saturation is L_s , that after drying is L_d and the shrinkage is:

$$S_h = \frac{L_s(inmm) - L_d(inmm)}{L_s(inm)} \quad \text{in mm/m}$$

d) Freezing-thawing resistance

This concrete property is determined by testing decrease of compressive strength or of dynamic Young-modulus in consequence of frost action. The test method is an accelerated one: the concrete specimens will be exposed to frost during some hours then they will be put under water of temperature of +15 or +20 °C for some hours. This process will be repeated many times (10, or 20, or 50 or 100 times).

Freezing-thawing resistance should be tested on concretes according to Chapter 3.23/b.

The best method is investigation of decrease of dynamic Young-modulus the under influence of freezing-thawing process because on the basis of results it can be drawn the time change of decrease according to Figure 28.

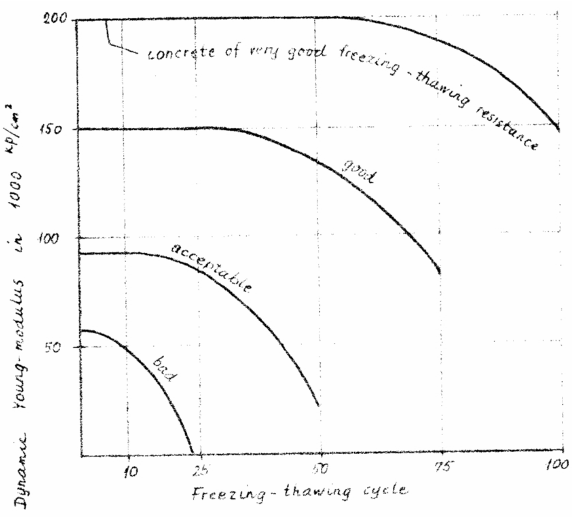


Figure 28.: Freezing-thawing resistance

e) Thermal conductivity

Thermal conductivity (λ) is quantity of heat expressed in kcal which passes in steady sate heat condition through layer perpendicular to the current of heat convection. Thickness of the layer is 1 m and its surface is 1 m^2. The difference of temperature of two surfaces of layer should be 1 °C.

For testing thermal conductivity many methods are known (e.g. instruments of Poensgen, that of Bock or of Nusselt). The type of specimens (form and size) is determined by the used instruments.

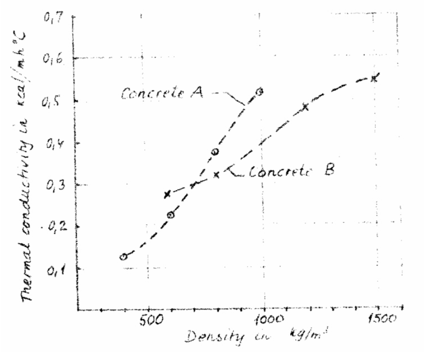


Figure 29.: Relationship between density and thermal conductivity

To investigate thermal conductivity it should be made the following specimens:

Thermal insulating concrete	Compressive strength kp/cm^2	5	10	35		
	Density kg/m^3	400	600	800		
Intermediate concrete	Compressive strength kp/cm^2				50	100
	Density kg/m^3				1200	1500

The thermal conductivity is influenced mainly by density, therefore it should be paid attention to this property in the course of manufacturing concrete. The results shall be drawn according to Figure. 29.

f) Water absorption

Water absorption can be investigated on any kind of specimens (cube, cylinder, prism, plate etc.). The specimens will be dried at temperature of +105 °C, then saturated with water.

To expel air bubbles from the concrete it is advisable to put specimens only in a few water (to height of water level should be 2 cm at the beginning of investigations) and after every one hour the water level should be raised with 2 cm. The quantity of absorbed water should be often measured and the investigation shall be continued until no difference can be determined between two consecutive measurements.

To investigate water absorption should be made specimens according to Chapter 23/a. The results of investigations shall be drawn according to Figure 30.

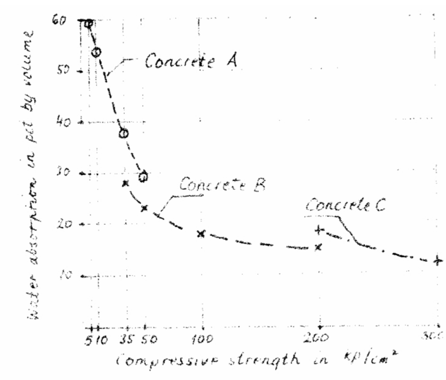


Figure 30. Investigation of water absorption

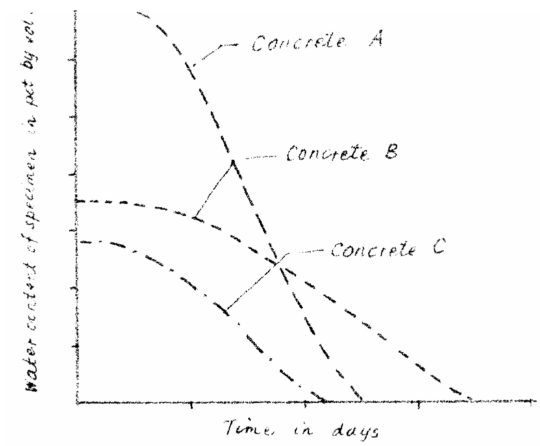


Figure 31.: Investigation of water desorption

g) Speed of drying

The concrete specimens saturated with water should be placed in determined climate (e.g. air humidity = 65 %, temperature = +20 °C). The specimens should be weighed until no difference can be determined between two consecutive measurements.

To investigate speed of drying should be made specimens according to Chapter 23/a. The results of investigations shall be drawn according to Figure 31.

3.24. Complementary investigations

Properties of concrete are influenced by more factors. To investigate effect of certain factors is needed for getting satisfactory knowledge about lightweight aggregate concrete. In the course of complementary investigations we shall determine:

a) effect of type of sand on density and compressive strength;
b) effect of type of sand on bending strength;
c) effect of type of sand on Young-modulus;
d) effect of cement content on bending strength;
e) effect of compacting method on bending strength;
f) effect of cement content on shrinkage;
g) effect of content and type of sand on shrinkage;

h) effect of air-entrainer on freezing-thawing resistance;
i) effect of air-entrainer on water absorption;
j) effect of air-entrainer on speed of drying;
k) effect of steam curing on shrinkage;
l) effect of steam-curing on shrinkage.

a) Effect of type of and n density and compressive strength

In the course of investigations up till now the grist of lightweight aggregate was used as sand. Now it should be controlled the effect of natural sand (grist of hard dock) on density and compressive strength. The grain distribution of aggregate should be as follows:

0 – 1,19 mm natural sand (grist of hard rock) = 35 pct by weight
1,19 – 4,76 mm lightweight aggregate = 30 pct by weight
4,76 – 25,4 mm lightweight aggregate = 35 pct by weight

We make concretes of the following composition:

Type I cement : aggregate : water by weight = 1 : 2 : (0,70)
Type IV cement : aggregate : water by weight = 1 : 5 : (1,45)

Remark: Calculation of water content = the water required by cement is the same as in Chapter 3.22/b, i.e. 20 pct of cement weight. The water required by aggregate is however less than in Chapter 3.22/b, since th natural sand does not absorb as much water as lightweight sand.

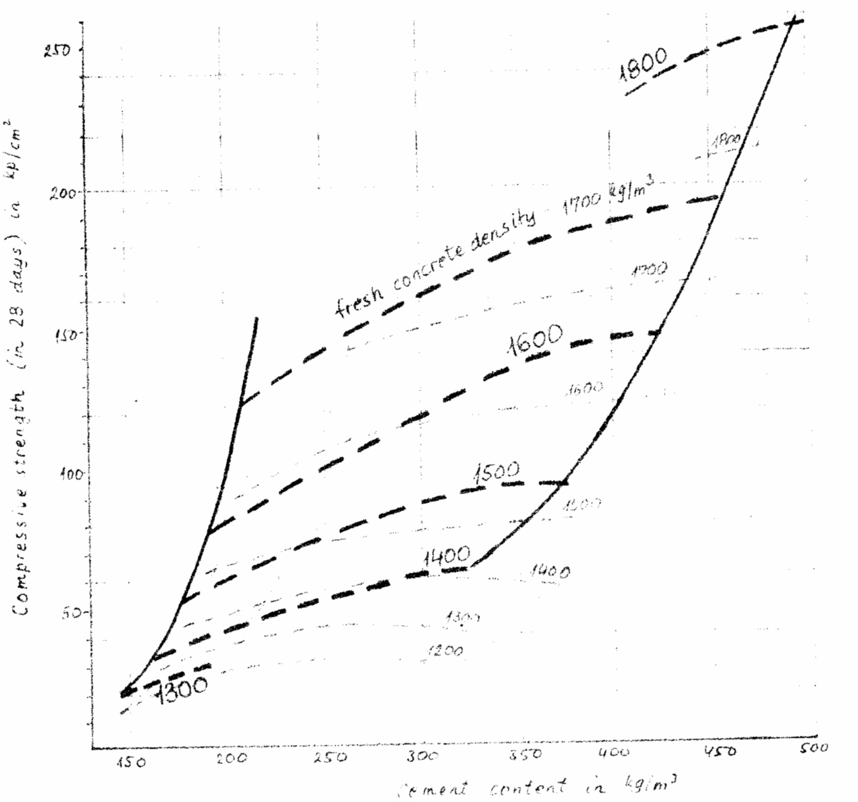


Figure 32. Construction of relationship among cement content, density and compressive strength for concrete made with natural sand (hard sand)

The mixing and compacting are the same, as in Chapter 3.22/b and the results of investigations should be drawn according to Figure 20. For construction of relationship among cement content, density and compressive strength from these results we have to use the relationship got from investigations of Chapter 3.22/b s it can be seen in Figure 32. In this Figure the thin lines signify the results of Chapter 3.22/b (see Figure20.) and heavy lines signify the results of these investigations.

b) Effect of type of sand on bending strength

On the basis of investigations according to Chapter 3.24/a three composition should be chosen from strongly or medium compacted mixtures of about following compressive strength: 50 kp/cm^2, 100 kp/cm^2 and 200 kp/cm^2. For choosing it should be used Figure 32. The results shall be compared with results of Chapter 3.23/a and drawn according to Figure 33.

c) Effect of type of sand on Young-modulus

Young-modulus of concrete made with lightweight sand was investigated according to Chapter 3.23/b. The effect of natural (hard) sand on Young-modulus shall be investigated on concretes of compressive strength of 100 kp/cm^2 and of 200 kp/cm^2(see Chapter 3.23/b). The results can be evaluated according to Figure 34.

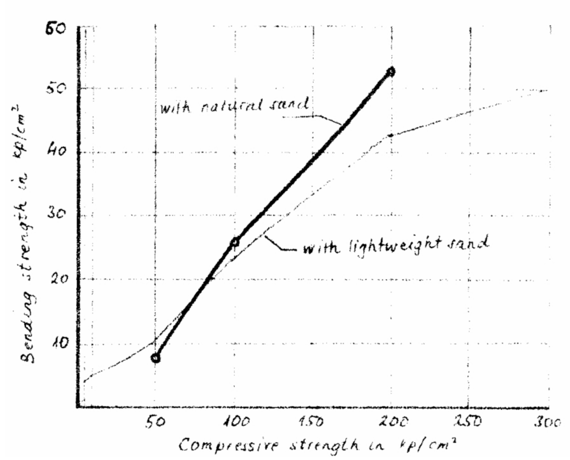


Figure 33. Relationship between compressive strength and bending strength

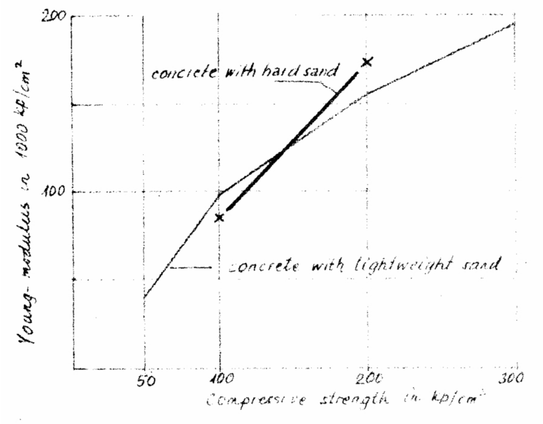


Figure 34. Relationship between compressive strength nd Young-modulus

d) Effect of cement content on bending strength

On the basis of Figure 20. it should be chosen four mixtures of the same compressive strength.

Example:

The chosen compressive strength should be 100 kp/cm^2: The concretes are to be made:

	A	B	C	D
Cement content in kg/m^3	210	250	300	400
Density in kg/m^3	1620	1580	1560	1550

Concrete "A" should be compacted very strongly, concretes "B"-"C"-"D" require gradually less and less compacting effect.

Results of investigations are to be drawn according to Figure 35.

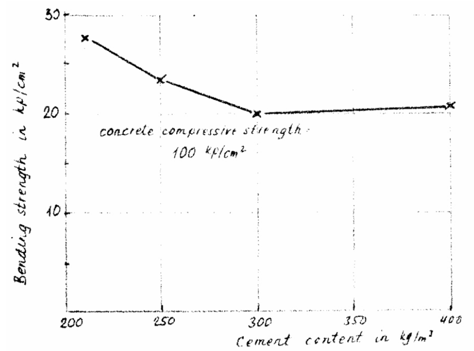


Figure 35.: Relationship between cement content and bending strength

e) Effect of compacting method on bending strength

On the basis of Figure 20. it should be chosen one mixing ratio (e.g. cement : aggregate . water = 1 : 3 : 1,1). After mixing concrete should be compacted with different methods (e.g. shaking, ramming, stamping, vibrating, vibrating+pressing). We have to make specimens for testing compressive strength and bending strength. The results shall be drawn according to Figure 36., where the results of investigations according to Chapter 3.23/ (Figure 25.) can also be seen.

f) Effect of cement content on shrinkage

This effect shoukd be tested on concretes according to Chapter 3.24/d (compressive strength = 100 kp/cm^2, cement contents and compacting effects are changed). The results shall be drawn according to Figure 37.

g) Effect of content and type of sand on shrinkage

This effect should be tested on concretes according to Chapter 3.24/b (compressive strengths = 50, 100 and 200 kp/cm^2, cement contents and compacting effects are to be chosen according to Figure 32.). The results shall be drawn according to Figure 38., where the results of investigations according to Chapter 3.23/c can also be seen.

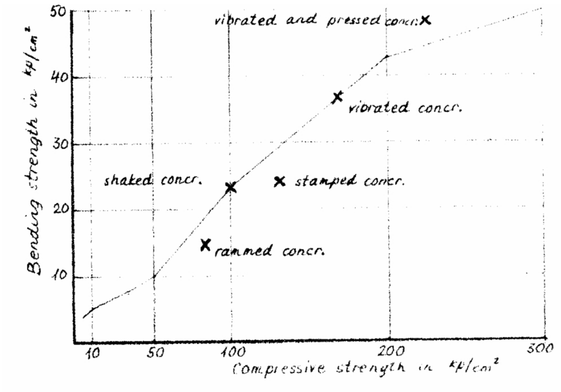


Figure 36.: Relationship between compressive strength and bending strength

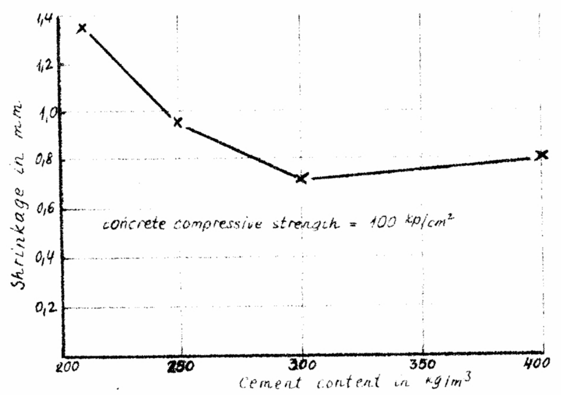


Figure 37.: Relationship between cement content and shrinkage

h) Effect of air-entrainer on freezing-thawing resistance

This effect should be tested on concretes according to Chapter 3.23/b, i.e. on concretes of compressive strength of 50, 100, 200 and 300 kp/cm². The effect of air-entrainer additive can be seen in Chapter 3.22/c.III and in Figure 24.,the mixtures should be chosen on the basis of their information. The results of this Chapter are to be compared with that of Chapter 3.23/d, where testing freezing-thawing resistance without additive can be found.

The results shall be drawn according to Figure 39.

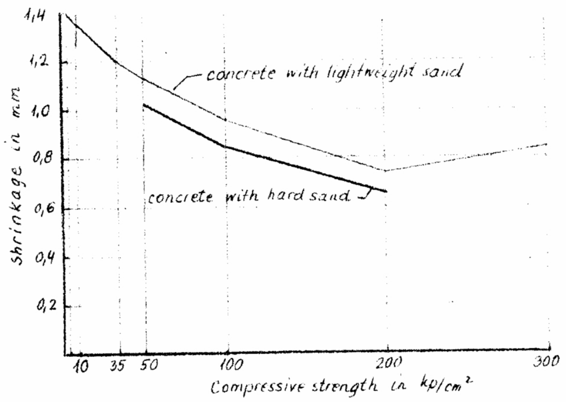


Figure 38.: Relationship between compressive strength and shrinkage

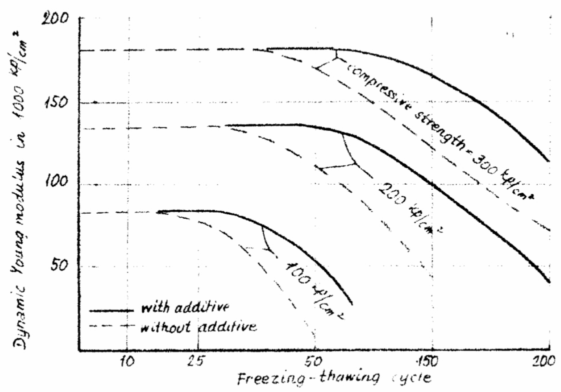


Figure 39.: Relationship between air-entrainer content and freezing-thawing resistance

i) Effect of air-entrainer on water absorption

Concrete without additive were tested at work of Chapter 3.23/f and the results can be seen in Figure 30. Now we make concretes of following compressive strength: 10, 35, 50 and 100 kp/cm², since the water absorption is remarkable mainly in thermal insulating and intermediate concretes.

The results of investigations shall be drawn according to Figure 40.

j) Effect of air-entrainer on speed of drying

Concretes without additive were tested in the course of Chapter 3.23/g and the results can be seen on Figure 31. Now we make concretes according to Chapter 3.24/I and the results shall be drawn according to Figure 41.

k) Effect of steam curing on compressive strength

For the sake of rise in the productivity of concrete production a wide-spread method is the steam-curing of fresh concrete. Setting cement is an exotherm process, the more the exotherm heat the shorter is the setting time. Exotherm heat is influenced by outer circumstances, first of all by the air-temperature. Unless watched evaporation of water on effect of high temperature the concrete will quickly dry, crack or in the worse case cement becomes incapable of hardening. Steam-curing is usable to ensuring water supply and high temperature in the same time. Steam-curing is advantageous method since it promotes the active SiO_2 of fine aggregate and Cao evolved of cement to be bound. This process increases concrete strength.

Method of steam-curing is influenced by many factors: type of cement and aggregate, cement and water content, density of concrete etc. by "method" is meant period and temperature of steam-curing.

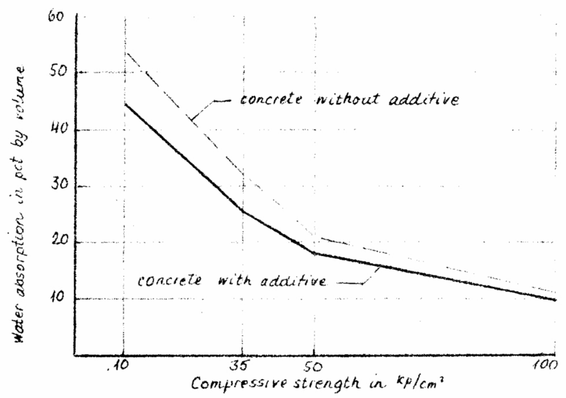


Figure 40. Relationship between air-entrainer content and water absorption

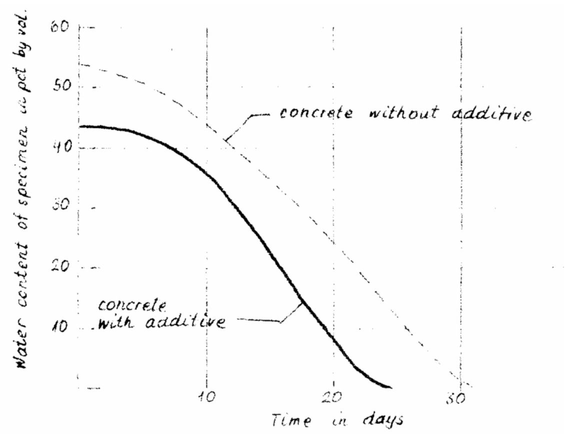


Figure 41.: Relationship between air-entrainer content and speed of drying

After these preliminary remarks the program of investigations is as follows.

Specimens should be made with concretes of following compressive strengths: 5, 35. 100 and 200 kp/cm^2. After compacting specimens should be stored in room of temperature of +20 °C and humidity of about 65 % during 1,5 hour. Then they will be put into steaming equipment and heated during 2 hours up to the following temperatures: 60 °C, 70 °C and 80 °C. Time of steam curing at the given temperature = 6 hours, time of cooling down to +20 °C = 1,5 hour.

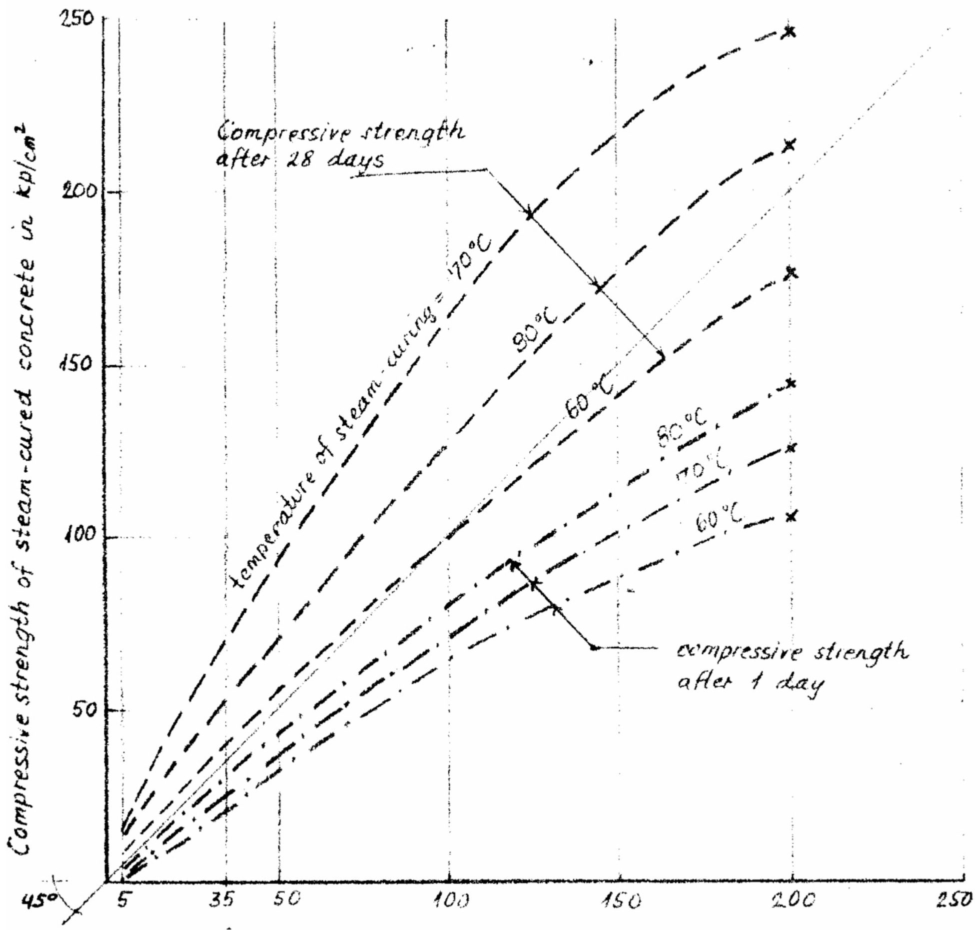


Figure 42.: Results of investigation of steam-curing

One series of specimens contains nine pieces. Three pieces will be stored in room (temperature +20 °C, air-humidity 65 %), six pieces will be steamed. From steamed specimens three pieces will be tested after 24 hours, three pieces after 28 days. On the basis of results the following features can be calculated:

C_{R1} = relative compressive strength of 1 day
C_{R28} = relative compressive strength of 28 days

Base of comparison is compressive strength in 28th day of specimens stored in rooms:

$$C_{R1} = \frac{\textit{compressive strength of steamed concrete in } 1^{th} \textit{ day}}{\textit{compressive strength of normal concrete in } 28^{th} \textit{ day}} \times 100$$

$$C_{R28} = \frac{\textit{compressive strength of steamed concrete in } 28^{th} \textit{ day}}{\textit{compressive strength of normal concrete in } 28^{th} \textit{ day}} \times 100$$

The results shall be drawn according to Figure 42.

l) Effect of steam curing on shrinkage

Steam curing changes generally the shrinkage of concrete. To investigate this effect six specimens should be prepared. Three of them shall be stored in room (temperature: +20 °C, air humidity: about 65 %) and their length should be measured after 24 hours.

Three other specimens shall be steam cured at temperature proved to be best in the course of investigations according to Chapter 3.24/k. Length of steamed specimens should be measured after 24 hours.

The results shall be drawn according to Figure 43.

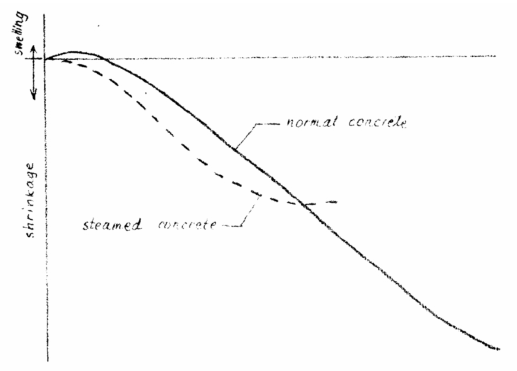


Figure 43.: Results of investigations of shrinkage

3.25 <u>Unforeseeable difficulties of concrete research work</u>

Concrete properties *are influenced* by a number of known and probably more unknown factors. Great part of known factors can be found in Chapters . and 2. *One could almost say*, that n the course of investigations *every single* one of these influencing *factors can be followed with attention*. It is not at all unlikely, that during investigations faults are crept into their results.

Therefore evaluating data we *must immediately draw* (or sketch) every possible relations, e.g. after measuring bulk density f fresh concrete se sketch the relationship between cement content and bulk density or that between water content and bulk density.

Furthermore *we must put down every circumstances* of investigations (e.g.: “In the course of mixing and compacting specimens H5 – H16 the door of laboratory was open, outer temperature +3 °C, inner temperature +17 °C” etc.).

For the sake of collection of facts, information, data *we can use only bound minute-book*, which is to be kept as a diary. This minute-book should be paginated before beginning of investigations. We *must not tear out any page* from this book.

If we find any result contradictory to the known or hypothetical (presumed) relationship we must repeat the investigations.

I should have liked to render palpable by the above that concrete-research – as every research-work – does not go straight, does not walk on the beaten track, but it clambers up narrow, untrodden paths and on this way the special knowledge is the single compass.

3.26. Number of specimens

We have to make the following specimens with one type of aggregate:

General investigations (3.22/b): 4 mixing ratios x 4 compacting effects x 3 specimens =	48 specimens
Effect of aggregate fine content (3.22/c.I): see Table of Chapter =	42 specimens
Effect of water content (3..22/c II): 2 mixing ratios x 6 water contents x 3 specimens =	36 specimens
Effect of air-entraine additive (3.22/c III): see Table of Chapter =	<u>45 specimens</u>
3.22. Technological investigations =	171 specimens
Bending strength (3.23/a) : 7 concrete types x 3 specimens =	21 specimens
Young-modulus (3.23/b): 4 concrete types x 3 specimens =	12 specimens
Shrinkage (3.23/c): 7 concrete types x 3 specimens =	21 specimens
Freezing-thawing resistance (3.23/d): 4 concrete types x 3 specimens =	12 specimens
Thermal conductivity (3.23/e): 5 concrete types x 3 specimens =	15 specimens
Water absorption (3.23/f): 7 concrete types x 3 specimens =	21 specimens
Speed of drying (3.23/g): new specimens are not needed, we use specimens of water absorption resting (3.23/f)	
3.23. Detailed investigations =	102 specimens
Effect of sand-type on density and compressive strength (3.24/a): 2 mixing ratio x 4 compacting effects x 3 specimens =	24 specimens

Effect of sand-type on bending strength (3.24/b): 3 concrete types x 3 specimens =	9 specimens
Effect of cement content on Young-modulus (3.24/c): 2 concrete types x 3 specimens =	6 specimens
Effect of cement content on bending strength (3.24/d): 2 mixng ratios x 3 specimens =	12 specimens
Effect of compacting method on bending strength (3.24/e): 5 compacting methods x 3 specimens x specimen-types =	36 specimens
Effect of cement content on shrinkage (3.24/f): 4 mixing ratios x 3 specimens =	12 specimens
Effect of sand-type on shrinkage (3.24/g): 3 concrete types x 3 specimens =	9 specimens
Effect of air-entrainer on freezing-thawing eesistance (3.24/h): 4 concrete types x 3 specimens =	12 specimens
Effect of air-entrainer on water absorption (3.24/i): 4 concrete types x 3 specimens =	12 specimens
Effect of air-entrainer on speed of drying (3.24/j): it is used specimens of above (3.24/I) investigation =	---
Effect of steam-curing on compressive strength (3.24/k): 4 concrete types x 3 temperatures x 9 specimens =	108 specimens
Effect of steam-curing on shrinkage (3.24/l): 2 storages x 4 concrete types x 3 specimens =	24 specimens
3.24 Complementary investigations =	264 specimens
Total =	***537 specimens***

It can be seen that many specimens are to be made. But it must be taken into consideration that in the program the minimum research-work is given so that the number of specimens must not be decreased.

The investigations must be carried out in one rate: it must be used one transport of cement (about 1,2 tons), one transport of aggregate (about 5 m^3) and production of specimens must be finished in determined time with the same collaborators. The results will be only in this way evaluable.

APPENDIX 2

PROGRAM
OF PERLITE INVESTIGATIONS ON LABORATORY AND PILOT PLANT SCALE

by

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September 1975, Rejkjavík

1. PURPOSE OF INVESTIGATIONS

Purpose of investigations is determining quality of perlite expanded pilot-plant furnace at Akranes in the course of its putting into operation and to test the products made with this perlite as well. Further purpose is to make preparations for pilot-plant production of different perlite products and in the course of this work to test the simple equipments advised to pilot-plant production.

2. METHOD OF INVESTIGATIONS

The laboratory investigation methods of expanded perlite quality are given in UNIDO reports (1), (2) and in report of ÉTI (3). In the curve of laboratory investigations should be tested bulk density, self-strength and grading of perlite (it is advisable to investigate the grains under microscope) and the relationship among cement content, compacting method, density and compressive strength for concretes made with perlite.

The methods of pilot-plant investigations depend on products to be made for industrial using. The recommended products are as follows:

a) Loose perlite: hydrophobized perlite;
perlite mattress
perlite insulating layer for floors and flat roofs

b) Perlite insulation with binder (cement, lime, gypsum, waterglass, bitumen):
perlite mortar for wall insulation (cement, lime, gypsum);
perlite mortar for fire proofing (cement, gypsum);
flat perlite plate for wall and roof insulation (cement, lime, gypsum, waterglass, bitumen);
perlite units for pipe insulation (cement, bitumen);
perlite cladding for steel construction (cement, gypsum).

c) Perlite partition walls and masonnary units :
perlite plates for partition walls (cement, gypsum, waterglass)
perlite masonnary units (cement).

d) Perlite in agriculture.

e) Perlite as filter-aid material.

3. PROGRAM OF INVESTIGATIONS *

3.1. Laboratory investigations

3.11. Properties to be tested

a) Test of perlite properties (grading, bulk density and self strength). In the course of pilot-plant expanding more perlite sorts will be expanded. Each sort should be tested separately. From the expanded material of one perlite sort average sample should be taken out, i.e. samples of small quantity (max. 1 litre) should be taken out of more places (min. 10) of expanded perlite heap and these samples should be mixed. This mixed perlite will be used to the tests. Necessary equipments:
- sieve series: it can be used either USA or British Standard sieves, i.e.
- scales of accuracy ± 1 g
- cylinder vessel of 1-10 litres (height equals diameter)
- testing cylinder with press-plunger (see Ref 3).

* Figures can be seen after text

b) Test of concrete properties. From the expanded material of one perlite sort average sample of 200 litres should be taken out. With concrete specimens made from this sample the relationship will be tested among binder content, compacting effect, density and compressive strength. Necessary equipments:
   - scale of accuracy ± 1 g,
   - vessels for weighing binder, perlite and water,
   - laboratory mixer,
   - doctor knife (steel-ruler) for forming specimens surface,
   - moulds of 40x40x160 mm,
   - pressing plate to making perlite concrete prisms (see in Fig.1.),
   - complementary frame (see in Fig.2.),
   - fog-chamber for curing specimens (+20 °C and 98 % air humidity),
   - chamber with air conditioner for curing specimens (+20 °C and 65 % air humidity),
   - material testing apparatus (10 – 5000 kg).

3.12 Performance of investigations

Testing method of grading, bulk density and self-strength can be seen in paper (4) and UNIDO report (1). Investigations method of relationship among binder contact, compacting effect, density and compressive strength was written in UNIDO report (2) and ÉTI report (3). Investigation results of perlite properties should be summarized in Table:

Perlite sort	Bulk density in kg/m^3	Self-strength in kp/cm^2	Abrams fineness modulus

and in Figures: grading curve and relationship between bulk density

To investigate concrete properties the following mixing ratio should be choosed (presumption: perlite bulk density is 80 kg/m^3):

Type I	cement : perlite : water by weight	=	1 : 1,0 : (2,2)
Type II		=	1 : 0,7 : (1,6)
Type III		=	1 : 0,5 : (1,2)
Type IV		=	1 : 0,3 : (0,8)
Type V		=	1 : 0,2 : (0,6)

Calculation of water quantity = 20 pct of cement + 200 pct of perlite.

After mixing bulk density of concrete shall be measured and 5 x 3 specimens should be made. The first three specimens should be made without compacting (the mixture will be poured loosely into moulds). For the second three specimens the complementary frame should be placed on the mould and the mixture shall be poured into it that its height of 4 cm (compacting effect: 50 pct). The third three specimens should be compacted with effect of 100 pct (height of loose mixture is 8 cm), then the following 2 x 3 specimens shall be made with compacting effect of 150 pct and 200 pt as well (height of loose mixture is 10 and 12 cm as well). The frame for making perlite concretes with different density can be seen in Figure 1. and 2.

The specimens will be cured in the first 7 days in a fog-chamber, after in climate chamber (see 3.11/b). Investigations will be carried out after 28 days (density, bending strength and compressive strength) and from the results the relationship should be drawn according to Figures 14. – 18. of Ref (3).

Similar investigations can be performed with other binders, If we have the results of test of perlite concrete bound with cement, the other binders need not investigations of the same quantity but only with extreme mixing ratios (e.g. Type 1 and Type V). The intermediate values can be determined by interpolating.

The results of investigations can be summarized according to the Table of example.

3.2. Pilot-plant investigations

3.21. Material or units to be made

These investigations have been two goals: to make products for training the technology on one hand and to make products for exhibition, fr marketing purposes on the other.

3.21.1. Loose perlite

In the course of pilot-plant expanding usual perlite and hydrophobized perlite should e made. The quantity of usual perlite ought to be about 30 m^3, that of hydrophobized perlite about 5 m^3.

With usual perlite it shall be made perlite mattresses and insulating layer for floors. In the course of this pilot-plant production shall be performed as follows:

Example: Results of investigation:

Mixture type	Bulk density of concrete in kg/m^3	Density of fresh concrete in kg/m^3	Cement content in kg/m^3	Perlite content		Water content in l/m^3	Calculated dry-density in kg/m^3	Compressive strength in kp/cm^2
				in kg/m^3	in l/m^3			
I	240	240 360 480 600	57 86 114 143	57 86 114 143	710 1040 1420 1790	126 188 252 314	125 180 250 315	0.1 2.6 6.0 15.0
II	260	260 390 520 650 780	74 118 158 197 236	55 83 110 138 166	690 1040 1380 1720 2070	126 189 252 315 378	150 225 300 375 750	0.1 2.7 7.5 15.8 30.2
III	280	280 420 560 700 840	107 156 208 260 310	52 78 104 130 155	650 980 1300 1620 1940	124 186 248 310 375	180 265 355 440 525	0.1 2.8 7.6 16.8 32.5
IV	300	300 450 600 750 900	143 215 286 357 428	43 64 86 108 128	580 800 1080 1350 1600	114 171 228 285 344	215 320 430 535 600	0 2.0 7.0 15.1 32.7
V	320	320 480 640 800 960	178 266 356 444 533	36 53 71 89 107	450 660 890 1110 1340	106 161 213 267 320	250 370 500 620 745	0 0.8 5.3 13.1 37.7

The results are drawn in Figure 3.

a) Minimum three perlite mattresses shall be manufactured for exhibition. One of them can be hung on a holder (see Figure 4.), the other will be layed and provided on its upper surface with concrete cladding (see Figure 5.) possibly it can be placed on a provisional roof (see Figure 6.). For training the technology of utilisation it is needed minimum 80 mattresses and roof (in industrial building or apartment house) of surface about 100 m^2.

b) Minimum 2 m^2 perlite layer should be made for exhibition (see Figure 7.). On a wood (or metal) plate combined frame from wood and glass (three walls from wood and one wall from glass) should be placed. The hardly moistened perlite (water of 50 litres to 1 m^3 perlite) will be poured into the mould and rolled. On surface of perlite layer cladding should be made from prefabricated concrete plates (perhaps from pumice-concrete) and provided with water-proof covering.

Minimum 100 m^2 perlite layer should be made for training technology, it is showed by Figure 8. after mixing perlite and water (see Figure 8/a) the mixture will be filled between guiding-bars and smoothed with simple tools (see Figure 8/b and 8/c). Then it will be compacted and smoothed with roll (see Figure 8/d), drying canal will be pressed on its surface (see Figure 8/e) and the surface will be covered with prefabricated concrete plates (see Figure 8/f).

In the course of this work three small plates should be made for testing speed of drying according to Figure 9. From thin metal plate (e.g. tin plate) moulds will be made (see Figure 9/a) and these moulds will be lined with plastic foil (see Figure 9/b). Into the lined moulds perlite-water mixture will be filled and rolled (see Figure 9/c). On the mixture surface one drying-canal will be formed (see Figure 9/d) and the specimens will be covered with plastic foil (see Figure 9/e). For ensuring the drying through the drying-canal gaps should be opened in the foil (and in light metal frame-walls) at two ends of canal (see Figure 9/e).

After weighing specimens (mould + perlite + foil) will be placed into a climate room (air-humidity 65-70 pct, temperature +20 ^oC). They should be weighed up till the time as the weight does not change. Decrease in weight can be drawn according to Figures 8.-13. of Ref. (3).

3.21.2. Perlite insulation with binder

a) Perlite mortar for wall insulation.

Using perlite mortar on walls improves their thermal insulation. In the course of pilot-plant investigations the properties of mortar will be controlled and the method of preparing mortar will be trained.

Mortar mixtures should be made with cement, lime and gypsum as binder. The mixing ratio shall be chosen on the basis of laboratory investigations (see Chapter 3.12.). Presumably mixing ratios are as follows:

cement : perlite : water = 1 : 0,5 : 1,2 and 1 : 0,3 : 0,8
lime-hydrate : perlite : water = 1 : 0,3 : 0,9 and 1 : 0,2 : 0,7
gypsum : perlite : water = 1 : 0,3 : 0,9 and 1 : 0,2 : 0,7

From each mixture shall be made about 100 litres. These mixtures will be used for exhibition purposes: therefore we have to make concrete plates (walls) of surface of about 2 m^2. Keymesh-lath should be fastened to the surface and the perlite plaster will be carried up the wall by the usual plastering instruments (trowel, floating-tool etc.). Thickness of plaster layer shall be about 30 mm.

From mortars specimens of 4x4x16 cm should be made to investigate their compressive strength. Quantity of specimens: 9 prisms from one mixture. Testing terms: at age of 7, 14 and 28 days. Storage and curing of specimens: at the same conditions as for the mortar on the wall.

Large wall surface should also be marked out to train technology of making perlite plaster. For this purpose it can be advised the new building of Building Research Institute in Keldnaholt. The technology can be seen in Figure 10.

b) Perlite mortar for fire-proofing

Different shafts in buildings (for electrical installations, sewage conduit, water pipes etc.) re generally dangerous during conflagration since they carry the flames. Therefore different solutions were carried out for their closing. One of them is the extremely lightweight perlite mortar. Its light weight can be ontained by air-entrainer additive.

To make perlite fire-proofing mortar controlled mixer should be used since its mixing effect higher than of gravity mixes.

Mixing ratios should be as follows:

cement : perlite : water : additive = 1 : 0,3 : 0,72 : A and 1 : 0,2 : 0,54 : B
gypsum : perlite : water : additive = 1 : 0,3 : 0,8 : A and 1 : 0,2 : 0,6 : B

"A" means: the maximum additive content according to its specification
"B" means: higher additive content than the prescribed maximum.

c) Perlite concrete plates for wall and roof insulation

A wide range use of perlite – perhaps in the greatest quantity – is the thermal insulation of the roof structure of industrial halls and either floor or roof of living houses with perlite concrete, This is normally cast in situ

or prefabricated, the roof may be either steeply or mildly sloping and level. Both precast units or monolithic concrete may be applied for insulation. In any case a due number of ventilation ducts (drying canals) of sufficient cross-section are needed to maintain continuous aeration of perlite concrete or to ensure drying out in case of eventual soaking (or of mixing water in monolithic concrete).

Plate for roof insulation can be seen in Figure 11/a. For plot-plant production simple moulds and pressing instrument can be made. The mould is composed of a detachable frame (Figure 11/c) and an underplate, its height is higher of 50 pct, than the required height of this insulating plate (according to the Figure: the height of insulating plate is 8 cm and that of the mould is 12 cm. It is to be noted that height of mould depends on result of investigations in Chapter 3.12.). On pressing instrument and mould can be found half-wedges for forming gaps of drying canal and mortar bed. Jointing of insulating plate can be seen in Figure 11/b.

Processing method: the perlite-cement-water mixture will be filled into the mould, after smoothing its surface in pressing machine the material will be pressed to the required height. After pressing the mould can be disconnected and the perlite-plate on underplate can be transported into storage. Curing: three-four days in fog-chamber, then in normal climate (65 % air humidity, +20 ^{o}C temperature).

Making roof insulation perlite plate shall be laid into underbedding made from mortar for equalization of roof surface.

For investigation of suitability of hydrophobic perlite for making lightweight (polystyrene-like) concrete, about 1 m^3 hydrophobic perlite should be prepared. Perlite concrete units should be made according to the above outlined processing method. Required quantity comes to about 50 units. Before the pilot-plant manufacturing laboratory investigations should be carried out with hydrophobic perlite. The mixture of cement, hydrophob perlite and water should be compacted in prisms (4x4x16 cm) under different pressure (see Chapter 3.12., Type I, III and IV mixing ratios, Figure 1. and 2. as well).

d) Monolithic perlite concrete for roof insulation

Perlite may be shipped to the site in bags. Before using, the perlite bulk density has to be checked. The mixing ratio determined by trial mixing may be kept until a deviation not more than ± 10 % is observed between the average perlite bulk density and that applied in the trial mix. In case of higher duration, another trial mixing is needed to determine the perlite concrete composition.

Cement has to be dosed by weight, both perlite and water may be added either by volume or by weight. Mixing is normally done in controlled (impeller-type) mixer because of the resulting perfect homogeneity and in spite of crushing the perlite particles.

If only a gravity mixer is available, this one will be operated with horizontal axis. To make full use of the drum capacity, the input opening should be covered. It is advisable to introduce cement and water first and to add perlite to the mixed laitance. Perlite is rather dusting, a dust mask is needed to protect mixer operator from silicosis.

Perlite concrete is less sensitive to transport than ordinary concrete because of its lower drying rte. Nevertheless it is advisably placed as soon as possible after mixing. If longer time (e.g. 2 h) has to be reckoned with between mixing and placing, then the water dosage has to be adjusted to maintain the specified density after transport. Water excess is not over 5-8 pct. as a rule.

The surface of roof should be cleaned from contamination, dust etc. The perlite concrete is to be poured between guide-rails and compacted either by manual or mechanical rammer of big surface, compacting roller, platform vibrator, plate vibrator etc. Poker vibrator must not be applied.

In course of manufacture, fresh density of perlite concrete has to be systematically controlled. In-situ cast perlite concrete is easy to sample by taking a sample of determined volume, to be weighed for determining its density.

After placing perlite concrete have to be protected for a few days both to train and to drying quickly (by wind, sunshine etc.): an impermeable layer (e.g. plastic foil) should cover the concrete surface. Thereafter, concrete drying out has to be forwarded. To promote drying the above mentioned drying canals should be applied.

Processing technology and sectional drawing of roof structure can be seen in Figure 12. In this Figure the steps of technology can be followed up: in Part A the cleaning the roof, in Part B the guide-rails and the perlite concrete placing, in Part C the compacting by roll, in Part D the drying-canals, in Part E the covering the drying canals by thin plates, in Part F the protecting the surface against rain, wind etc. by plastic foil, in Part G the grouting, in Part H the final water-proofing and in Part I the cross section of roof-structure can be seen.

e) Perlite for pipe insulation

Utilisation of perlite for pipe insulation may be either loosely or in form of prefabricated perlite concrete units.

One of the application of loose perlite needs a similar technology to the well-known insulation with foamed polyurethane. In workshop the pipes are supplied with protective outer tubes of larger diameter than pipes and into gap, instead of polyurethane, loose perlite will be poured. For prevention of dropping perlite from the gap, plastic foil will be glued to the two ends of pipe-units and – for ensuring the immobility of outer tube and inner pipe during transportation – locks should be applied. This solution can be seen in Figure 13.

Other possibility to spare polyurethane: the gap will be filled in partly with polyurethane and partly with loose perlite. The processing technology: in the gap from one end of tube will be inserted a partition ring and the polyurethane will be expanded in the space from the other end of tube. Then the ring will be pulled out, perlite will be filled and it will be compacted slightly with the ring, then from the other end of tube will be closed by polyurethane. This method can be seen in Figure 14.

To determine possibility of utilisation and behaviour of pipes during transportation and mounting both varieties shall be investigated. For this purpose cca 50-50 metres experimental pipe-loine section should be made.

Utilisation of prefabricated perlite needs designing the form of insulating units to be applies. It is advisable to apply cross-section of quarter-arc. The units can be placed on surface of pipe in workshop and, for their fixing, impermeable band can be rolled up (sticked up) to the surface of perlite concrete (see in Figure 15.). For making perlite concrete units, simple pressing instrument can be applied (similar to Figure 11., but the cross-section is of quarter-arc).

f) Perlite cladding for steel construction

Lightweight mortar or concrete made with perlite are in general fire-proof, therefore thy provide satisfactory protection for steel constructions to the conflagration. Units made for vertical or horizontal structures are different. For horizontal structures are protected in general with ceiling, vertical structures with units fromed to cross-section of structures.

Gypsum perlite has outstanding refractory and fireproof characteristics. Steel structures coated by 2,5 cm of gypsum perlite resist to fire during 1 hour. Remind, however, the increased importance of architectural design of the fireproofing layer or structure to fire by applying a gypsum perlite suspended ceiling, rather than a plastering, leaving an appropriate air gap between ceiling and structure may result in a floor that keeps its fire resistance during 4 hours of fire.

Notwithstanding the fireproof characteristics of cement bound expanded perlite is rather less than that of gypsum bound one, the perlite concrete bound with cement provides also satisfactory protection for steel construction against conflagration.

3.21.3. Intermediate concrete from perlite

In this group the self-sustaining units and load-bearing units can be includes: partition walls and masonnary units.

a) Partition walls

Lightweight partition walls can be prefabricated from perlite bound with either cement or gypsum. In the course of pilot-plant trials, the perlite bound with cement will be tested. Measurement of units depends on the available equipments. Possibilities of processing methods:

- manufacture horizontally on plane concrete surface, compacting by stay-plate vibrastor. Bx this method small units can be made only (see Figure 17.);
- manufacture horizontally on plane concrete surface, compacting by platform vibrator. By this method also large units can be made (see Figure 16.). Large units can be expediently made with mixing of fibres into the perlite concrete;
- manufacturing horizontally under pressure (see Figure 19.);
- manufacturing vertically under pressure (see Figure 20.).

Every unit should be made with rabbets according to Figure 21. These rabbets serve for bed of mortar t join the units. It is advisable to form round-cornered rabbets, since the angular rabbets can be compacted with difficulty. Building technology can be seen in Figure 21.

b) Masonnary units

Masonnary units can be prefabricated from perlite bound with cement. Equipment of production is the "vibropress". Every vibropress machine used for making ordinary concrete masonnary units is suitable for manufacturing perlite concrete units.

Mixing ratio depends on compacting effect of the available vibropress-machine in Iceland. The water content may be mainly changed: in the case of low compacting effect the water quantity should be more than in the case of higher compacting effect. The composition (mixing ratio) of perlite concrete should be based on results of investigation in Chapter 3.12. Required compressive strength is minimum 35 kp/cm^2.

Before the pilot-plant production, trial mixing should be performed. Perlite concrete shall be mixed with mixing ratio chosen from results of investigation in Chapter 3.12. and compacted in vibropress-machine. After compacting density of fresh concrete should be immediately determined. If the density is lower than the required one (than the result of investigation in Chapter 3.12.) water quantity should be increased. If the density is higher, then water quantity should be decreased.

Usual masonnary unit can be seen in Figure 23.

In the course of pilot-plant production, min. 500 masonnary units should be made and cca 30 m^2 wall built with these units.

3.21.4. Hydrophobic perlite for water cleaning

Water contamination by oil can be cleaned with hydrophobic perlite. This material dies not absorb water but, on its large surface, it adsorbs oil. The grains remain floating on water surface and perlite saturated with oil can be easily removed (e.g. with fine-tooth rake).

For demonstration of hydrophobic perlite characteristics, water surface contaminated with oil should be prepared (e.g. platter of 2-3 m^2 surface, deep of 0,3-0,4 m full with water and 2-3 litres oil pouring to it). From perlite 4-5 litres will be poured on surface and after saturation of the grains with oil, the perlite will be removed by rake. This process can be repeated until the water surface will have been cleand.

3.21.5. Perlite for other purposes

Utilization of perlite for agricultural purposes and as filter-aid material should be also investigated during the pilot-plant testing, but program of this work can be found in other paper.

3.22. Required quantity of materials to the investigations

Every single investigation requires the following quantity of materials:

- Chapter 3.1. Laboratory investigations: perlite: 0,1 m^3; cement: 0,02 t; gypsum: 0,01 t; lime-hydrate: 0,01 t.
- Chapter 3.2. Pilot-plant investigations:
  - Chapter 3.211. Loose perlite:
    a) perlite mattresses (insulation of 100 m^2 surface): perlite: 16 m^3, plastic foil sacks: 80
    b) perlite layer (insulation of 100 m^2 surface with perlite covered with prefabricated concrete plates of 40x40x4 cm)): perlite: 15 m^3, concrete covering plates: 650
  - Chapter 3.21.2. Perlite insulation with binder:
    a) perlite mortar for wall insulation (wall surface = 100 m^2, plaster thickness = 3 cm): perlite: 6 m^3; cement: 1,1 t; gypsum: 0,1 t; lime-hydrate: 0,1 t; Keymesh-lath: 100 m^2.
    b) Perlite mortar for fire-proofing (for 1 m^3 mixture): perlite: 1 m^3; cement: 0,2 t; gypsum: 0,3 t; air-entrainer additive: 20 l.
    c) Perlite concrete plates for wall and roof insulation (100 m^2 surface, 650 plates of 40x40x8 cm): perlite: 14 m^3; cement: 2,5 t; perlite as well as perlite concrete (polystyrene-like) (50 units): hydrophobic perlite: 1 m^3; cement: 0,35 t.
    d) Monolithic perlite concrete for roof insulation (100 m^2 surface, 8 cm thickness): perlite: 14 m^3; cement: 2,5 t.
    e) Perlite for pipe insulation (50 metres with polyurethane + perlite, 50 metres with perlite only): perlite: 40 m^3; foamed polyurethane: 3,5 m^3.
    f) Perlite cladding for steel construction (ceilings: surface of 100 m^2 and thickness of 4 cm; prefabricated units: 100 pieces): perlite: 9 m^3; cement: 2 t; gypsum: 0,5 t.
  - Chapter 3.21.3. Intermediate concrete:
    a) partition walls (20 m^2): perlite: 2,5 m^3; cement: 0,8 t.
    b) masonnary units (500 units cca 15 litres concrete): perlite: 17 m^3; cement: 1,8 t.
  - Chapter 3.21.4. Utilization of hydrophobic perlite:
    Hydrophobic perlite: 0,05 m^3.

Summarizing:				
	perlite	134.6)	=	148 m^3
	hydrophob perlite	(1.05)	=	1,1 m^3
	cement	(11.27)	=	12 t
	gypsum	(0,91)	=	1 t
	lime-hydrate	(0.11)	=	0,12 t
	plastic foil sacks		=	80
	air-entrainer additive		=	20 l
	foamed polyurethane		=	3,5 m^3
	pipe-units (pipe and protecting tube)		=	100 m
	keymesh-lath		=	100 m^2
	concrete covering plates (40x40x4 cm)		=	1300
	water-proof covering		=	200 m^2

3.23. Required instruments, equipments to the investigations

It will be summarized the instruments and equipments required to the pilot-plant production and investigation.

- Chapter 3.21.1. Loose perlite
  a) perlite mattresses: 1 holder for exhibition purposes (see Figure 4.); 1 provisional roof for exhibition purposes (see Figure 6.); 1 filling equipment (with container of 2 m^3).
  b) perlite layer: gravity mixer (drum-volume: 200-300 litre); 1 vessel for water dosing; 1 hand-barrow; 1 frame-work for exhibition purposes (see Figure 7.); 120 m guiding-bar (wood or metal); 1 smoothing tool (2 m); 1 compacting roll (more than 100 kg); 2 m^2 provisional roof for exhibition purposes (see Figure 7.); 1 drying canal maker (see Figure 8/e); 6 light metal moulds (see Figure 9/a).
- Chapter 3.21.2. Perlite insulation with binder

  Equipments and instruments for mixing:
  - gravity mixer and controlled mixer (drum volume 2-300 litres);
  - vessel for water dosing;
  - weighing machine (min. 100 kg);
  - vessel for perlite dosing,
  - vessel for binder dosing

  Equipments and instruments for transportation of perlite concrete:
  shovel and hand-barrow.

  Other equipments and instruments are as follows:
  a) perlite mortar for wall insulation and fire proofing: trowel, floating tool, shovel, 9 prism-moulds (4x4x16 cm), hammer, pincher (to fasten keymesh-lath).
  b) perlite concrete plates for roof insulation: 1 mould and pressing instrument; 1 press machine (min. 20 t); 50 underplates (50x50 cm); 10 vent tubes (see Figure 12/I); brick-layers instruments; 1 mortar mixer (placing the plates).
  c) monolithic perlite concrete for roof insulation: broom; framework of wood (see Figure 12/b); roller (min. 150 kg); drying canal maker (see Figure 8/e); trowel;; floating tool; shovel.
  d) Perlite for pipe insulation: container; filling machine.
  e) Perlite cladding for steel construction: pressing machine; mould and pressing instrument; underplates.
- Chapter 3.21.3. Intermediate concrete from perlite
  a) partition walls: concrete surface (about 15 m^2); framework of wood; stay-plate vibrator; bricklayer's instrument.
  b) masonnary units: vibropress machine; filler (see Figure 22).

References:

(1) János E. Ujhelyi: Final Report about the Expert Activity Performed in Iceland on behalf of UNIDO. Budapest, March 1973

(2) János E. Ujhelyi: Industrial application of perlite in Iceland. Reykjavík September 1973

(3) János E. Ujhelyi: Scientific Report on investigations into properties of mortars and concrete made with Icelandic perlite made upon commission by the Government of Iceland. Budapest April 1975.

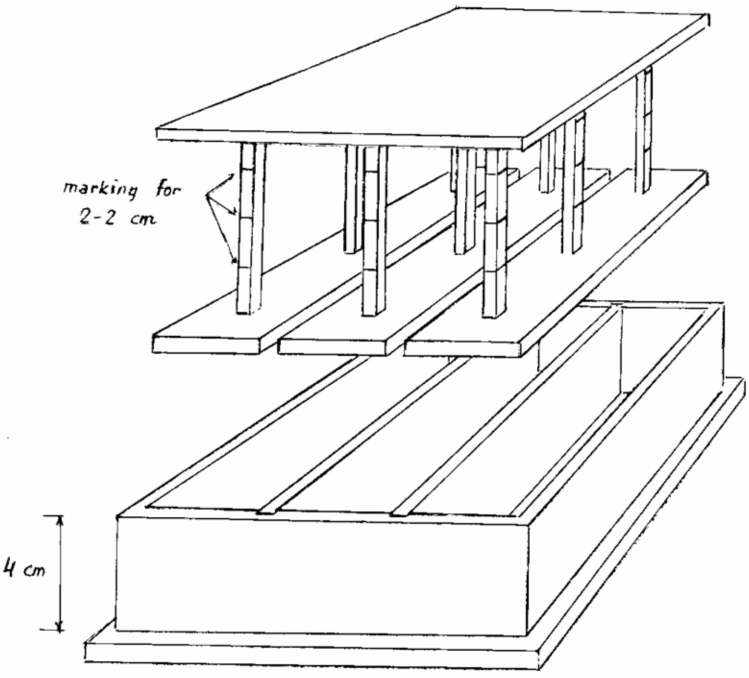


Fig. 1 : Pressing plate to making perlite concrete prisms

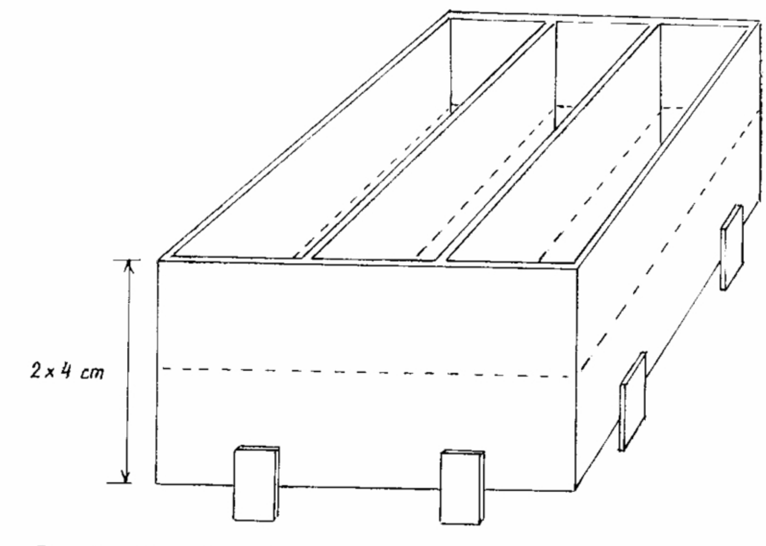


Fig. 2.: Complementary frame for making perlite concrete prisms

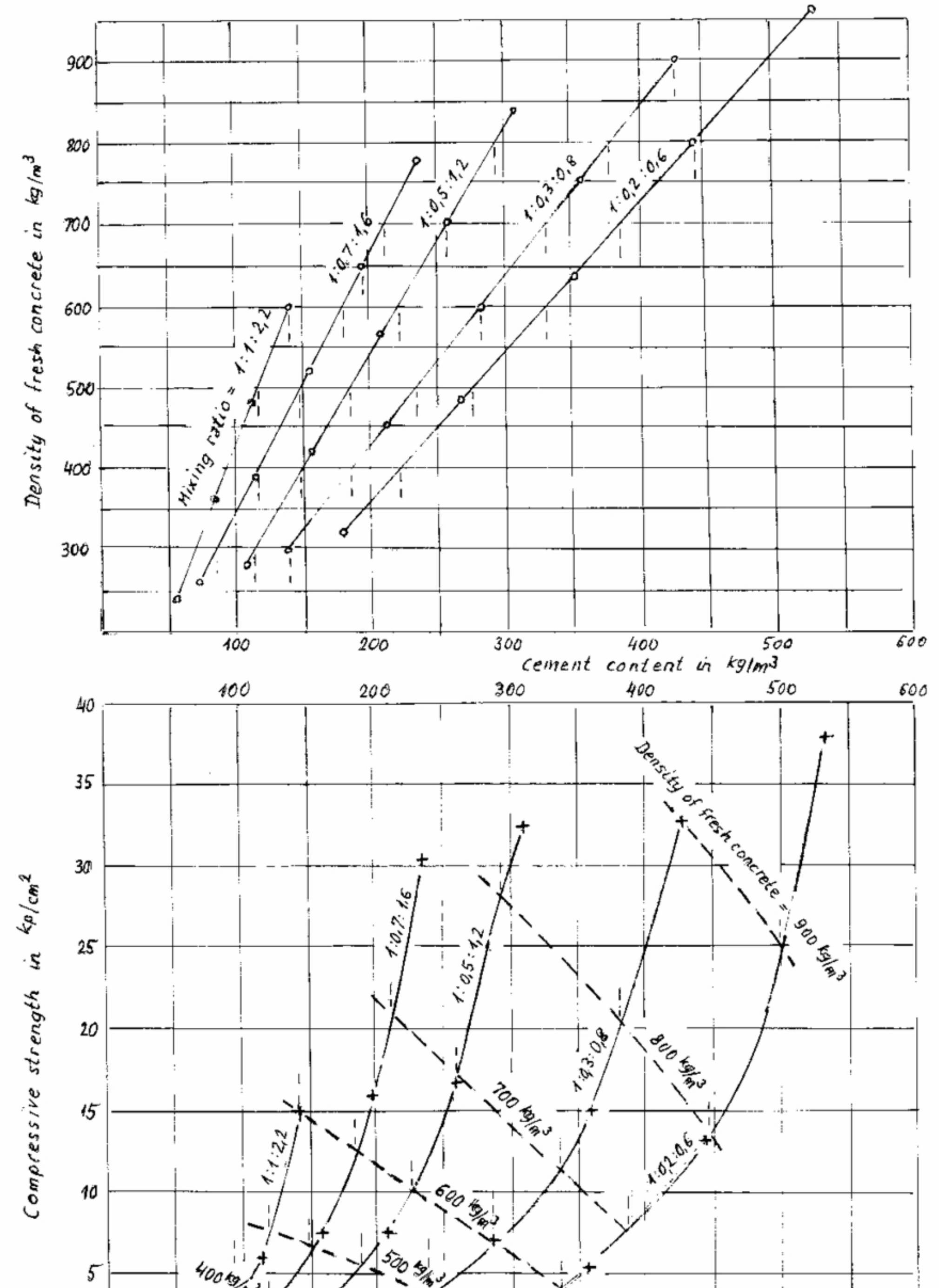


Figure 3.: Relationship among cement content, density, compacting effect and compressive strength on the basis of data of example (see Table)

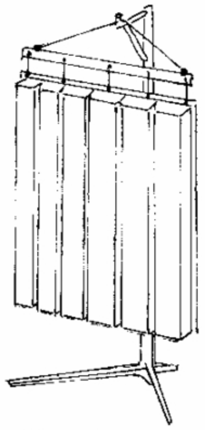


Fig. 4. Perlite mattress on holder for exhibition

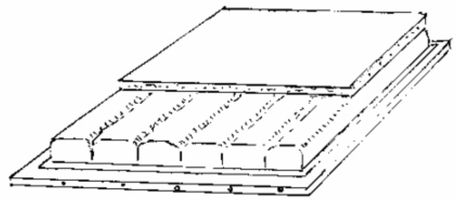


Fig. 5. Perlite mattress with concrete cladding

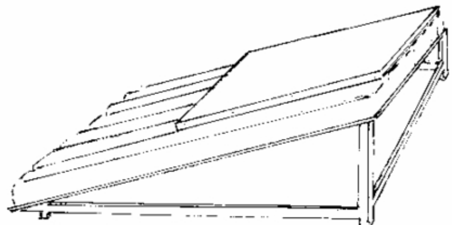


Fig. 6. Perlite mattress on roof

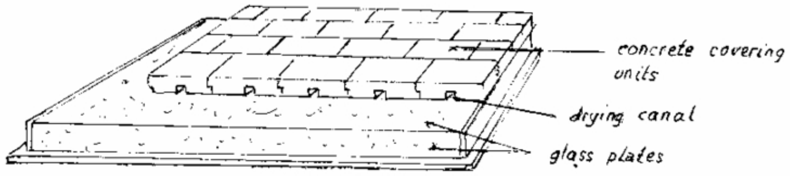


Fig. 7. Loose perlite layer for exhibition

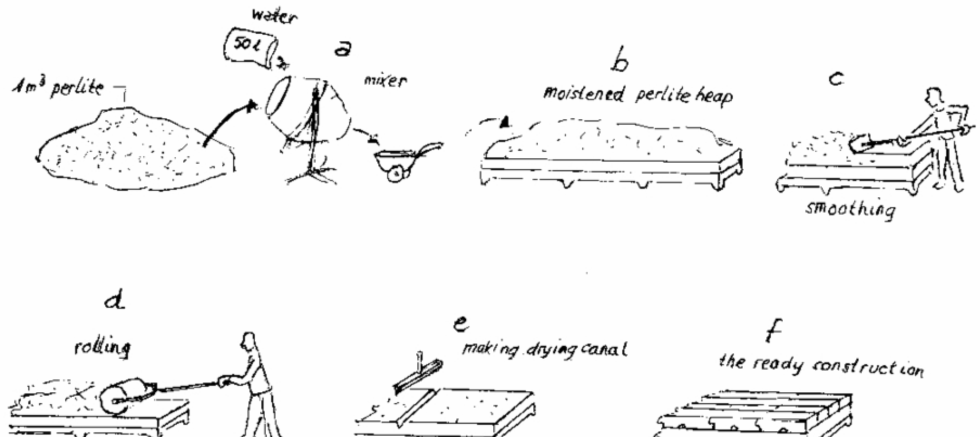


Fig. 8. Technology of making loose perlite layer

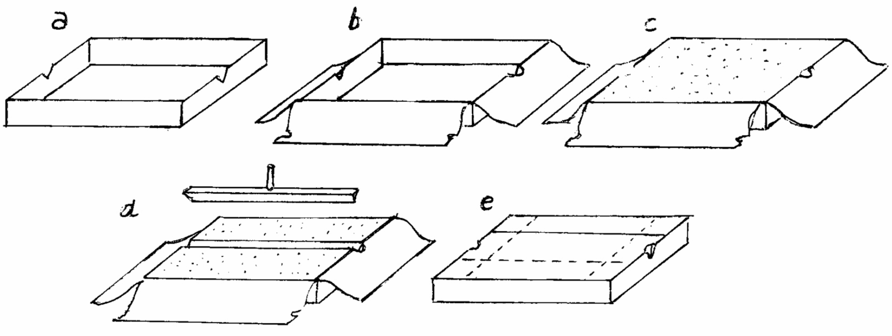


Fig. 9. Testing speed of drying of loose perlite

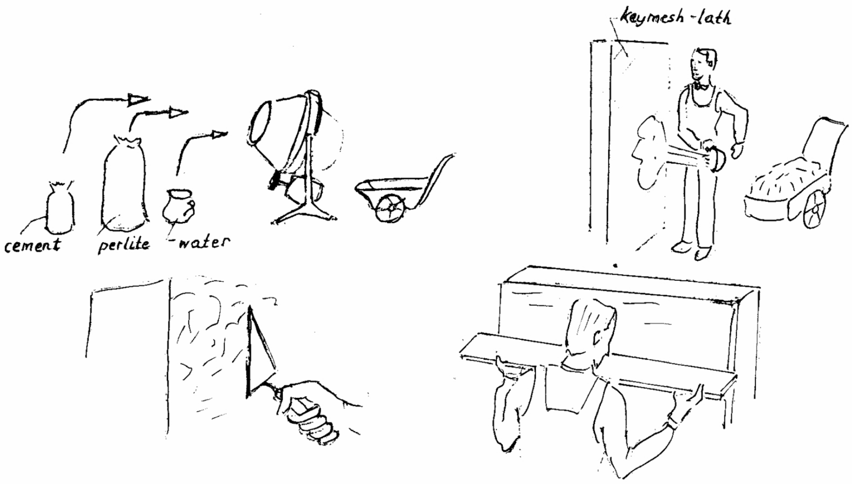


Fig. 10. Making perlite plaster

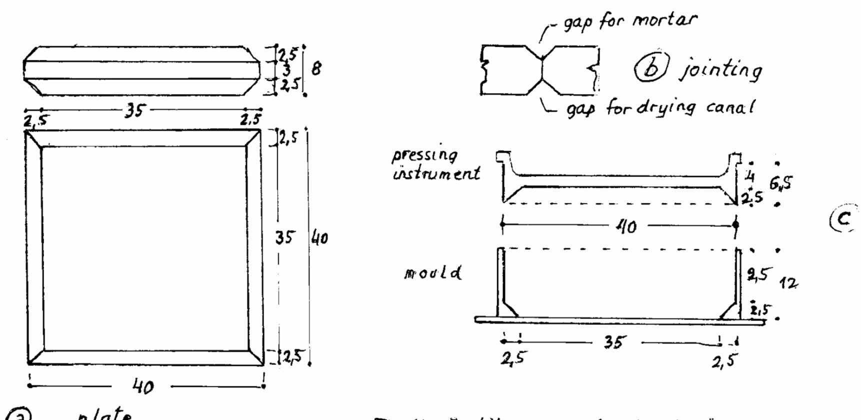


Fig. 11. Perlite concrete insulating plate

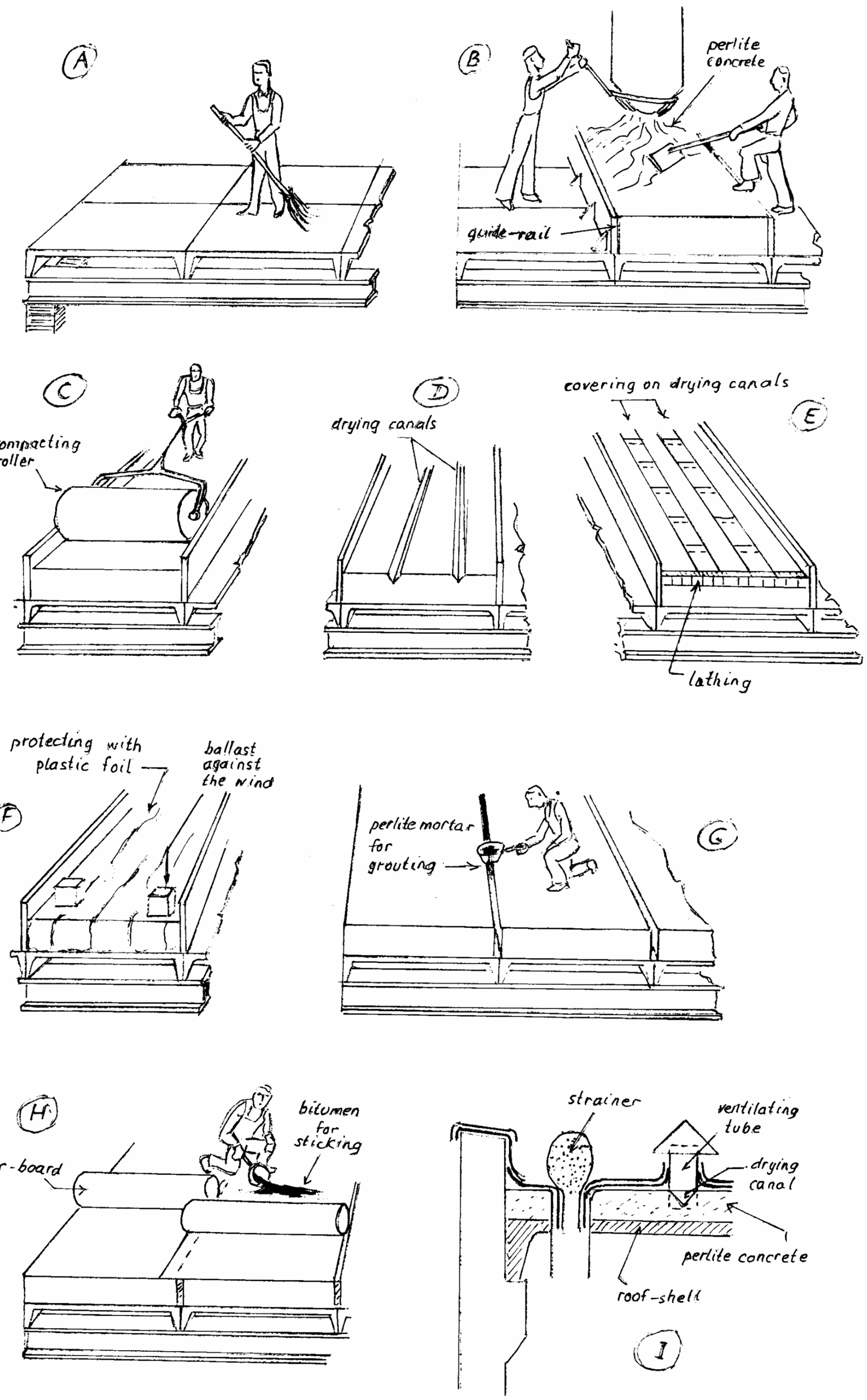


Fig. 12. Processing technology of in-situ perlite concrete roof insulation

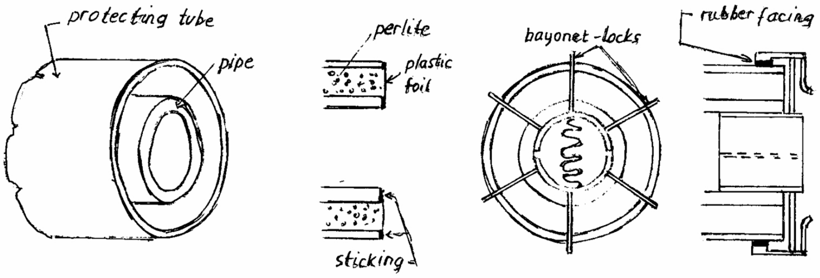


Fig. 13. Loose perlite insulation of heating pipe

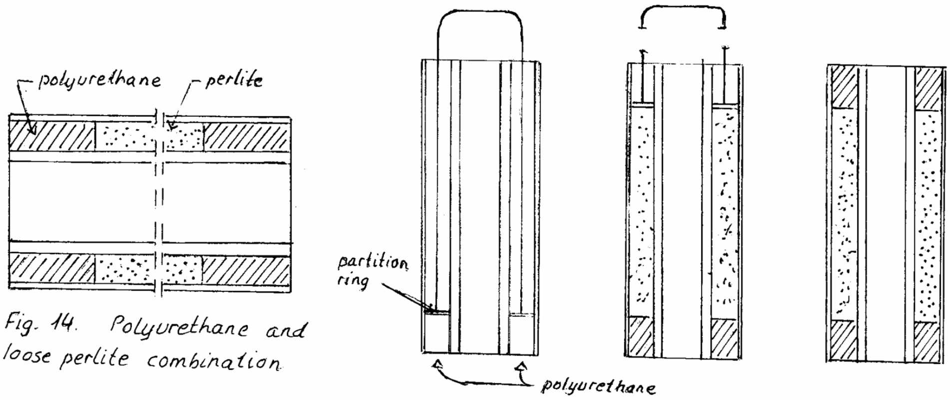


Fig. 14. Polyurethane and loose perlite combination

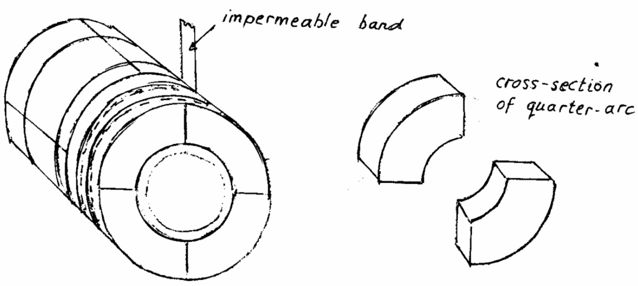


Fig. 15. Prefabricated perlite concrete for pipe insulation

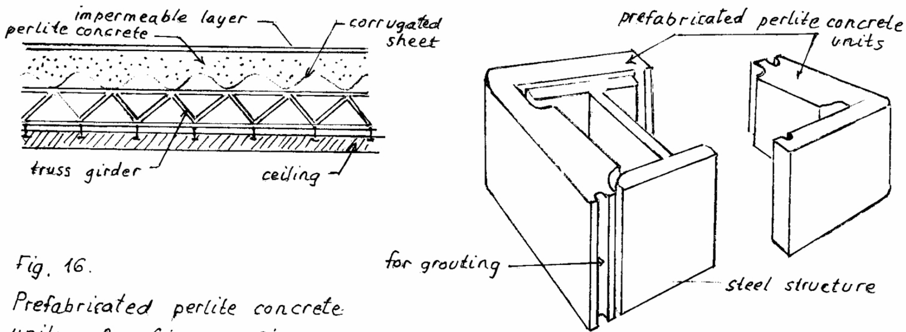


Fig. 16. Prefabricated perlite concrete units for fire-proofing

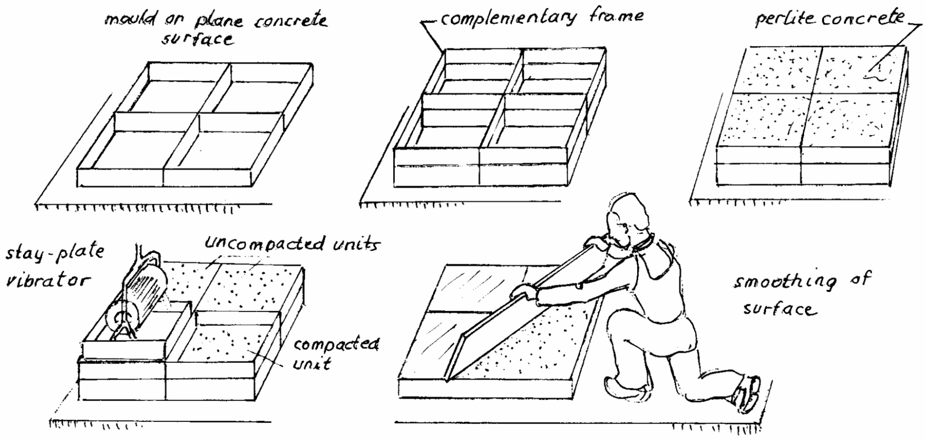


Fig. 17. Manufacturing of small partition wall units

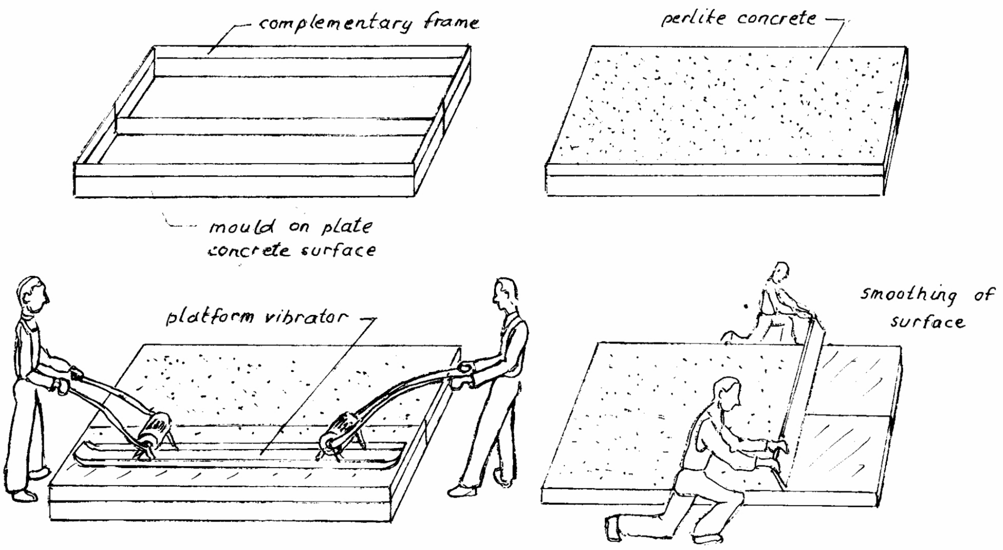


Fig. 18. Manufacturing of large partition wall units

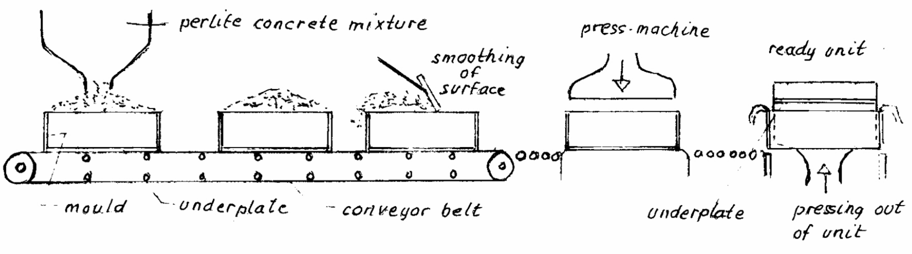


Fig. 19. Manufacturing of small partition wall units under pressure

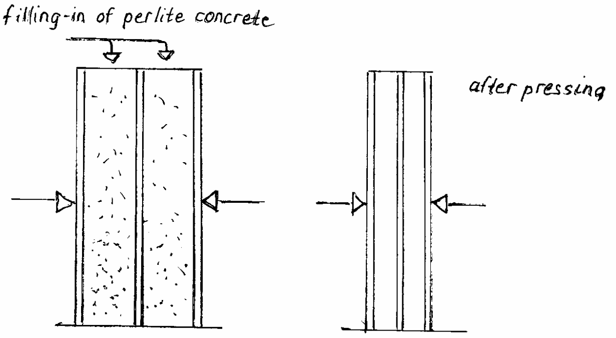


Fig. 20. Production of partition walls in vertical position

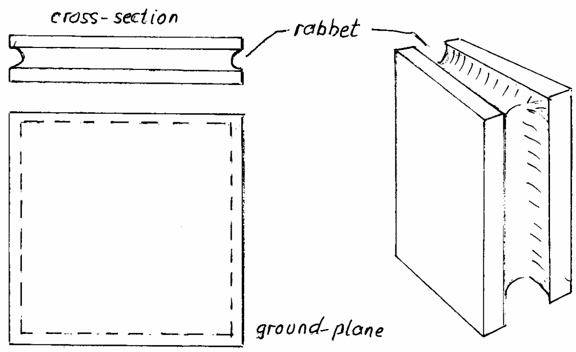
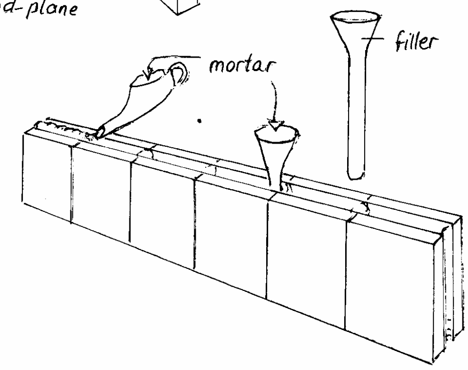


Fig. 21. Partition wall unit

Fig. 22. Building technology of partition wall with small-size units



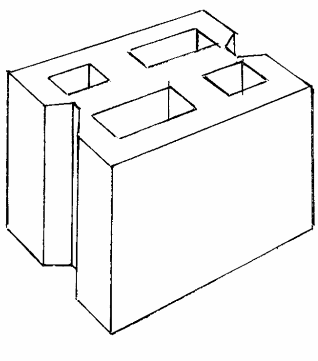


Fig. 23. Concrete masonnary unit

APPENDIX 3

FINAL REPORT
ABOUT INVESTIGAION OF ICELANDIC PUMICE AND SCORIA

Rejkjayík, October 1975.

by

Sigmundur Einarsson and Gylfi Einarsson
geologist geologist

under direction of
János Elemér Ujhelyi
Civil Eng., D.Ph., UNIDO expert

Tables and Figures are summarized after the text

This research was carried out in the Building Research Institute at Keldnaholt, Iceland (Director: Haraldur Åsgeirsson) on behalf of the Volcanic Material Committee in Iceland (Chairman: Hördur Jónsson IÞSf). The research was necessary for determining the properties of Icelandic pumices and scorias are available from Reykjavík. On the basis of results of this investigations it can be chosen materials are most suitable for internal utilisation and external marketing.

The program and method of investigations was specified by János E. Ujhelyi, the experiments were performed by Sigmundur Einarsson and Gylfi Einarsson. The Report was compiles according to the title page of this Report.

1. INTRODUCTION

Iceland has many volcanic materials which, because of their light weight and relatively high self-strength, are usable fr making building materials i.e. concretes. The building practice have proved the good characteristics of these materials, a few of them are exported recently and used in the internal market as well. But up to now there were no systematical research to determine the most important properties of the Icelandic lightweight aggregates and the most suitable processing methods for making concretes.

Utilization of lightweight aggregate concretes has more technical and economical advantages:

a) decreasing weight of concretes, the transportation costs can be decreased (transportation costs of aggregate, concrete mixture and prefabricated concrete as well;
b) decreasing weight of concrete, dead-load of constructions decreased, therefore either slender constructions can be made (decreasing the cross-sections) or span of constructions can be increased;
c) increasing the pore content of the concrete, the thermal insulating properties can be improved;
d) increasing the pore content of the concrete, the sound damping can be improved;
e) increasing the pore content of the concrete, the water evaporation can be improved;
f) influencing density of concrete, the inflexibility and brittleness can be improved;
g) decreasing weight of concrete structures, the foundation costs can be decreased;
h) decreasing density of concrete, multipurpose constructions can be produced (e.g. load-bearing and thermal insulating structure with) one material.

The lightweight concretes are products of the last few decades. The countries, where natural sources of light-weight aggregates are not available or only in a small quantity, have quickly developed their industry of artificial lightweight aggregates (expanded clay, sintered fly-ash). Really the properties of artificial aggregates can be influenced by processing method, therefore the best material can be produced. The price of these artificial aggre-gates, however , is in general so high that they are not able displace the natural ones even if the latter are lower quality. Utilization of lightweight aggregates has increased continually, used quantity of them came in the last years to number of million m^3 in the world (e.g. only in the USA the lightweight aggregate utilization is over ten million m^3/year).

It can be taken advantage of export possibilities if suitable results of investigations and experiences of industrial application are at disposal of deposit's owners. These results and experiences are needed for determin-ing the best using field of an aggregate. Without these the prices and the export marketing cannot be kept a firm hand on or developed.

It was the reason of decision of Volcanic Material Committee to begin with the research work of the Icelandic lightweight aggregates, i.e. developing the internal industrial application and the external marketing of these materials. The program of investigations can be found in Chapter 3. of paper in Appendix 1. In this report the first pert of investigation is summarized.

2. METHODS AND RESULTS OF INVESTIGATIONS

The most important properties of lightweight aggregates are as follows:

a) density of material or bulk density of grains;
b) self-strength either of material or of grains;
c) grading of the original material;
d) water absorption of grains.

The density (or bulk density) influences the density of concrete (and by this means the thermal conduc-tivity of concrete), the compressive strength of the concrete depends on self-strength of aggregate, from grading of original material it can be concluded the necessity of crushing and the water absorption of grains determines the mixing water requirements of concrete mixture.

Methods used for the investigations are ad follows:

Fifteen samples of lightweight materials were collected from different deposits (see Figure 1.). The ma-terials were dried et temperature of +105 °C and their bulk density, self-strength of grains, grading and water absorption were tested.

Investigation of bulk density: Material with a determined grain size distribution was put into a cylinder of known weight (W_c), without any compacting. Then the full cylinder was weighed (W_t).

$$\text{Bulk density} = (W_t - W_c) : V_c \quad \text{in kg/m}^3$$

where V_t is volume of cylinder.

Every sample was measured three times and the average value was calculated. The testing results of grain size 4,76 – 19,0 mm (50 pct 4,75 – 9,5 mm and 50 pct 9,5 –19,0 mm) can be seen in Table 1., that of grain size of 4,76 – 9,5 mm can be seen in Table 2. Om the basis of these results, relationship between bulk densities

investigated on grain-size of 4,76 – 9,5 mm and 4,76 – 19,0 mm cab be seen in Figure 2. The separated results are drawn in Figures 3. and 6.

Investigation of self strength: The material to be tested was put into a metal cylinder of known volume. From the bulk density the quantity of material was calculated which was needed to fill the cylinder. Then a fitting plunger was put on top of the material and the apparatus was placed into a testing press- The plunger was pressed up to prescribed up to prescribed depth (1 in and 2 in) and the force was measured. The self-strength is as follows:

$$A_s = F / S \quad in\ kp/cm^2$$

where F = force is needed to press the plunger up to 2,54 or 5,08 cm in kp; S = surface of plunger in cm^2.

Every sample was measured three rimes and the average value calculated. The same grading was used as in the case of bulk-density investigation. The results are summarized in Tables 3.-4. and in Figures 4. and 7. On the basis of results the relationship between bulk density and self-strength was drawn in Figures 5. and 8.

Investigation of grain-size distribution: From every sample5 kg were taken out and put into drier at temperature of + 105 °C. The dried samples were screened on ASTM-Standard sieves The amount of material lost during the screening was added to the 0-0,074 mm grain size.

The results are summarized in the Table 5., the grading curves can be seen in Figures 9., 10., 11., 12. and 13.

Investigation of water absorption: From every sample 700 cm^3 (in a few cases 1000 cm^3) were taken out put loosely into a glass cylinder without bottom. The cylinder was placed on a glass plate. After weighing the cylinder , the plate and the material sample, the instrument (plate and cylinder with sample) was placed in a vessel. Water was filled into the vessel up to 2 cm height and the water level was increased with 2 cm in every two hours. The instrument was weighed after 3, 20 and 70 hours. The water absorption in pct by Volume is as follows:

$$[(W_a + x + p) - (W_c + p)] \times 100 / W_a$$

where $W_a + x + p$ = weight of instrument with absorbed water in g; $W_c + p$ = weight f cylinder + plate in g; W_a = weight of investigated dry sample in g.

The results are summarized in Table 6. and Figure 14. Grading of investigated materials was: 30 pct 0-1,16 mm; 30 pct 1,16-4,76 mm; 40 pct 4,76-19 mm.

As it could be supposed pozzolanic properties of some lightweight volcanic materials, the pozzolanic effect was informatively investigated.

The scoria (Seyðishólar, Óbrynnshólar) and one pumice (Hekla HAF) were ground to fineness of cement (under 60 µm) and mixed with lime-hydrate and gypsum. Mixing ratio:

75 pct by weight of ground material
25 pct by weight of lime-hydrate
3 pct by weight of gypsum

and required quantity of water for getting good workability. The mixture was compacted by hand, prisms were cured in fog chamber during 25 days then in room climate, their strength was tested in 28 days age. The results can be seen in Table 7.

3. EVALUATION OF RESULTS

On the basis of results of investigations, the following conclusions can be drawn:

a) as regards the relationship between bulk density and self-strength, there are no difference between results of the two testing methods: cylinders of smaller and larger diameters (see Figures 5. and 8.);

b) the difference in bulk densities measure on 4,76-9,5 mm as well as 4,76-19 mm grains in practically constant; the bulk densities measured on 4,76-9,5 mm, however, are greater than that on 4,76-19 mm, i.e. the greater the grain size the lighter is the bulk aggregate (see Figure 2.);

c) Hekla HAF and Sandá pumices as well as Seyðisholar scoria are the best aggregates between the investigated materials as regards their relationship between bulk density and self-strength;

d) cylinders used to investigation of self-strength were different sizes; it can be stated that cylinder of larger diameter is more suitable for testing self-strength than the other, since in the larger cylinder the so called “wall-effect” of Faury predominates less (see Figures 4. and 7.);

e) the investigated materials are granuleous in their natural state, since the lightweight aggregate concretes require generally sandy aggregates (content of fine material of 0-1 mm should be about 30 pct) between the materials the Svartsengi scoria and Hekla, Sandá, Skógasandur and Hýrdalssamdur pumices can be used without crushing (see in Figure 13.), but the others must be crushed before their using. The crushing effect has not to be high, it is enough to use crushing roller;

f) water absorption of materials is of three types: that of Hekla and Sandá pumices and Seyðishólar scoria comes too about 40 pct by Vol., that of Vestmannaejar scoria is of 26 pct by Vol., that of the other materials is between 31-35 pct by Vol. It means that the Vestmannaejar scoria has the coarsest pores;
g) on the basis of results and experiences got from previous investigations in Hungary and the international literature, it can be expected that the following concrete properties can be obtained with the different materials;

Deposit	Expectable			
	Density in kg/m^3	Compressive strength in kp/cm^2	Cement content in kg/m^3	Thermal conductivity in kcal/mh°C
Svartsengi	1500-2200	35-400	150-500	0,45-1,10
Seyðishólar	1100-1800	25-300	150-450	0,25-0,65
Hekla HAF, Sandá	800-1700	25-300	150-450	0.20-0.60
Skógasandur, Mýrdalssandur, Kálfhólar	1300-1800-	25-200	150-400	0.35-0,65
Óbrynnishólar, Vestmannaeyjar, Hellisheiði, Tjarnarhólar	1100-1800	25-150	150-350	0.25-0.65

h) it can be stated unambiguously that big samples from Hekla-territory and Seyðishólar should be prepared for technological (detailed)investigations. For the estimated quantity of materials Table 8. gives information and in this Table distance of transportation can also be seen;
i) it seems to be advisable that every calculable lightweight aggregate in Iceland has to be searched and investigated to have the characteristics of materials which are important technologically. It is needed, because utilization of lightweight aggregate concrete can be advised to spread in the building industry in Iceland and to prepare the marketing of these materials abroad. For these purposes Code of Practice is to be made which contains the processing methods of manufacturing lightweight aggregate concretes and the properties of them for static's calculation on the one hand and constructions are to be made for references on the other;
j) it is advisable to make these investigations according the program written in Appendix 1.;
k) it is advisable to make also investigations for pozzolanic effect because e.g. Hekla HAF pumice gave very promising results

4. USING FIELD OF ICELANDIC LIGHTWEIGHT AGGREGATES

For determining using fields, the Table of Chapter 3/g can be taken into consideration. As the best materials are the Seyðishólar scoria and the Hekla pumice, these materials will be discussed.

Both materials are suitable to make concretes of presumed compressive strength between 25-300 kp/cm^2. It is known that concrete for load-bearing construction has to have compressive strength of min 150 kp/cm^2. This compressive strength is needed to ensure the good adhesion between steel-bars and concrete and the good protection of steel-bars against corrosion (namely in this case the density of cement-paste round the steel will be satisfactory. If the compressive strength of lightweight concrete made with either Seyðishólar scoria or Hekla pumice comes to 150-300 kp/cm^2 (see the Table) it can be calculated statically as an ordinary concrete, i.e. these lightweight aggregate concretes can be used in this range as the ordinary concrete of the same compressive strength.

Density of ordinary concrete can be taken in account with 2400 kg/m^3 therefore e.g. the weight of an ordinary concrete roof of surface of 6x6 = 36 m^2 and of thickness of 20 cm comes to 17,3 t. But density of Hekla pumice concrete of the same compressive strength (e.g. 300 kp/cm^2) can be taken in account with about 1600

kg/m^3, therefore the weight of the same roof comes only to 11,5 t. The difference is 5,8 tons in consequence of which the cross section of the roof can be decreased or the reinforcement of concrete can be weaker i.e. less expensive.

If the cross section of a concrete roof is decreased weaker supporters can be build, i.e. cheaper ones. Taking a simple example weight of a load bearing construction (4 columns of 30x30 cm and of height 3 m, roof of 6x6x0,2 m) made of ordinary concrete comes to 20 tons and made of lightweight (pumice) concrete comes to 13 tons. In consequence of sparing in dead-load of 7 tons, the costs of foundation can be decreased accordingly.

Other advantage of lightweight concrete is that it does not require thermal insulation or only lower quality of it because its thermal conductivity can be taken in account at design of building, by this means heat-transfer through the load-bearing construction can be eliminated.

Prefabrication of lightweight concrete load-bearing constructions is advantageous both technically and economically from the point of view of artificial curing. It is commonly known that compressive strength of a steamed ordinary concrete in age of 28. day is lower than that of the same concrete without steaming and post-hardening of the former is also smaller. If compressive strength of an ordinary concrete without steaming was 100 pct in age of 28 days, that of steamed concrete would only be about 80 pct and that of steamed lightweight concrete, however, comes to 100-120 pct. Prefabricating lightweight concrete constructions and steaming them, it is possible to spare cement.

Making lightweight aggregate concrete two disadvantageous properties should be taken into consideration. Its shrinkage is relatively higher and its Young-modulus lower than that of ordinary concrete. These properties, however, can be influenced by processing method on the one hand and by mixing ratios on the other. The lower Young-modulus can be also advantageous because in this case concrete is able to tolerate high deformation without cracking.

Other important property is the tensile strength or bending strength. Bending strength of lightweight aggregate concrete is higher than that of ordinary concrete of the same compressive strength. Values to be taken into account can be found in the technical literature. Lightweight concrete of compressive strength above 150 kp/cm^2 is of freezing resistance and it also has fire resistance during 1-2 hours and heat resistance durably is general up to +800 ^{o}C.

Processing method of lightweight aggregate concrete for load-bearing construction is similar to the ordinary concrete: after mixing it should be compacted effectively and its density and compressive strength can be influenced by good choice of mixing ratio.

Other great field of utilization is the intermediate concrete. Concretes are assigned to this group, which have compressive strength of 50-150 kp/cm^2. In this group Hekla pumice concrete have presumably density of max 1500 kg/m^3 and thermal conductivity of max 0,5 kcal/mh^{o}C, Seyðishólar scoria concretes have presumably density of max 1600 kg/m^3 and thermal conductivity of max 0,55 kcal/mh^{o}C. Under limit of density is presumed 1200 kg/m^3 and that of thermal conductivity is 0,3 kcal/mh^{o}C. These concretes have also higher sound-absorptive properties than the ordinary ones.

Concretes of these characteristics are suitable to be used to constructions which are required to have both load-bearing and either thermal insulating or sound absorptive properties in the same time. Such constructions are e.g. masonnary units, wall element, chimneys, collar-beams, partition walls, cushions, road-beds, planking of bridge, ceilings, different claddings etc.

Processing method of this concrete type differs from that of ordinary concrete in its compacting. Lightweight aggregate concretes in this group should be compacted with instrument which ensures both required density and compressive strength. The mixing ratio and the compacting effect should be brought in harmony.

5. SUMMARIZING

On the basis of investigations it could be stated that pumice from Hekla territory and scoria from Seyðishólar territory have good characteristics for making lightweight aggregate concrete. According to results of informative testing of pozzolanic effect it could be stated that Hekla pumice has also hydraulic features. Since these materials are suitable for making constructions in Iceland on the one hand and for selling them in external market on the other, it seems to be advisable to carry out detailed investigations for determining the processing method and the most important properties of concretes.

Table 1 Investigation of bulk density

Volume of cylinder : 2130 cm^3 Grain size : 4,76 – 19,0 mm

Deposit	Weight in kg	Bulk density in kg/m^3 single	average
Svartsengi (black)	1821	855	858
	1834	861	
	1829	859	
Óbrynnishólar (black)	1313	616	625
	1330	624	
	1350	634	
Óbrynnishólar (red)	1233	579	584
	1253	588	
	1245	585	
Hellisheiði (black) *	1058	501	502
	1055	500	
	1063	504	
Hellisheiði (red) *	1093	518	514
	1080	512	
	1080	512	
Seyðishólar *	1105	524	523
	1093	518	
	1110	526	
Kálfhólar *	1246	591	579
	1218	577	
	1198	568	
Tjarnarhólar *	990	469	477
	1010	479	
	1018	482	
Vestmannaeyjar *	1071	508	504
	1049	497	
	1070	507	
Hekla (HAF)	640	300	299
	640	300	
	632	297	
Hekla Sandá (coarse)	607	285	286
	607	285	
	611	287	

*) volume of cylinder : 2110 cm^3

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Table 2 Investigation of bulk density

Volume of cylinder : 600 cm^3 Grain size : 4,76 – 9,5 mm

Deposit	Weight in kg	Bulk density in kg/m^3	
		single	average
Svartsengi (black)	583 594 585	972 990 975	979
Svartsengi (red)	590 579 585	967 965 975	969
Óbrynnishólar (black)	410 386 401	683 643 668	665
Óbrynnishólar (red)	408 392 392	680 670 670	673
Hellisheiði (black)	353 362 366	588 603 610	600
Hellisheiði (red)	363 371 357	605 618 595	606
Seyðishólar	387 380 383	645 633 638	639
Kálfhólar	425 425 413	708 708 688	701
Tjarnarhólar	364 357 355	607 595 592	598
Vestmannaeyjar	378 385 372	630 642 620	631
Hekla (HAF)	250 258 232	417 430 387	411
Hekla Sandá (coarse)	204 207 207	340 345 345	343
Hekla Sandá (fine)	217 211 220	362 352 367	360
Skógasandur	445 441 440	742 735 733	737
Mýrdalssandur	430 437 431	717 728 718	721

Table 3 Investigation of self-strength

Pressed surface : 19,6 cm^2 Investigated quantity of material : 200 cm^3
Grain size : 4,76 - 19,0 mm

Deposit	Bulk density in kg/m^3	Weight of the investigated sample in g	Force in kp		Self-strength in kp/cm^2			
			at 2,54 cm	at 5,08 cm	at 2,54 cm		at 5,08 cm	
					single	average	single	average
Svartsengi (black)	658	172	950	6 000	48,4	45,8	307	297
			800	5890	40,8		300	
			930	5590	47,5		285	
Óbrynnishólar (black)	625	125	380	1670	19,4	17,7	85,2	86,7
			390	1770	19,9		90,3	
			270	1660	13,8		84,7	
Óbrynnishólar (red)	584	117	280	1450	14,3	15,3	74,0	71,9
			330	1430	16,8		73,0	
			290	1345	14,8		68,8	
Hellisheiði (black)	502	100	180	650	9,2	8,8	33,2	30,6
			130	590	6,6		30,1	
			210	560	10,7		28,6	
Hellisheiði (red)	514	103	170	620	8,7	8,5	31,6	34,4
			160	720	8,2		36,7	
			170	685	8,7		35,0	
Seyðishólar	523	105	405	1790	20,7	21,3	91,3	94,5
			420	1940	21,4		99,0	
			430	1825	21,9		93,3	
Kálfhólar	579	116	415	1795	21,2	20,8	91,6	89,0
			380	1770	19,4		90,3	
			430	1670	21,9		85,2	
Hekla (HAF)	299	60	560	1930	28,6	28,7	98,5	98,1
			530	1785	27,0		91,1	
			600	2050	30,6		104,6	
Hekla (Sandá, coarse)	286	57	590	1780	30,1	27,0	90,8	86,4
			490	1620	25,0		82,7	
			510	1680	26,0		85,7	

Table 4 Investigation of self strength

Pressed surface : 39,6 cm²　　*Investigated quantity of material : 550 cm³*
Grain-size : 4,76 - 9,5 mm

Deposit	Bulk density in kg/m³	Weight of the investigated sample in g	Force in kp at 2,54 cm	Force in kp at 5,08 cm	Self-strength in kp/cm² at 2,54 cm single	Self-strength in kp/cm² at 2,54 cm average	Self-strength in kp/cm² at 5,08 cm single	Self-strength in kp/cm² at 5,08 cm average
Svartsengi (black)	979	538	2000	7850	50,5	48,8	198,2	199,0
			1900	8500	48,0		214,6	
			1900	7300	48,0		184,3	
Svartsengi (red)*	969	533	1750	6850	44,2	44,2	173,0	173,0
Óbrynnishólar (black)*	665	368	490	1385	12,4	12,4	35,0	35,0
Óbrynnishólar (red)	673	370	640	1870	16,2	16,7	47,2	48,2
			680	1950	17,2		49,2	
Hellisheiði (black)	600	330	490	1145	12,4	12,8	28,9	29,0
			520	1150	13,1		29,0	
Hellisheiði (red)*	606	333	340	985	8,6	8,6	24,9	24,9
Seyðishólar	639	351	1890	4920	47,7	45,6	124,2	117,7
			1790	4590	45,2		115,9	
			1740	4470	43,9		112,9	
Kálfhólar	701	386	1320	3375	33,3	33,7	85,2	85,2
			1350	3370	34,1		85,1	
Tjarnarhólar *	598	329	450	1270	11,4	11,4	32,1	32,1
Vestmannaeyjar	631	347	510	1210	12,9	12,7	30,6	30,1
			495	1220	12,5		30,8	
			500	1150	12,6		29,0	
Hekla (HAF)	411	226	2370	4630	59,8	58,2	116,9	118,4
			2260	4495	57,1		113,5	
			2280	4940	57,6		124,7	
Hekla Sandá (coarse)	343	189	1260	3040	31,8	30,4	76,8	72,4
			1140	2690	28,9		67,9	
Skógasandur *	737	405	1445	3820	36,5	36,5	96,5	96,5
Mýrdalssandur*	721	397	1090	2975	27,5	27,5	75,1	75,1

* the available quantity of material was sufficient only for one testing

Table 5 Investigation of grain distribution of original materials

Deposit	Dimension	Sieve size <200	200	100	50	30	according to the British Standard 16	8	4	3/8	3/4	1	1½	2
	in mm	< 0,075	0,075	0,15	0,3	0,6	1,19	2,36	4,76	9,5	19	25,4	37,1	50,8
Svartsengi (black)	g	171	104	320	636	843	927	783	613	375	60	96	72	–
	pct	3,4	2,1	6,4	12,7	16,9	18,5	15,7	12,3	7,5	1,2	1,9	1,4	–
Svartsengi (red)	g	85	124	392	795	883	798	700	427	337	104	61	294	–
	pct	1,7	2,5	7,8	15,9	17,7	16,0	14,0	8,5	6,7	2,1	1,2	5,9	–
Óbrynnishólar (black)	g	605	270	387	381	323	420	1079	3145	5460	3640	4485	1775	3530
	pct	2,4	1,1	1,5	1,5	1,3	1,7	4,2	12,4	21,4	14,2	17,6	6,9	13,8
Óbrynnishólar (red)	g	70	74	108	121	110	119	248	832	1550	645	645	38	440
	pct	1,4	1,5	2,2	2,4	2,2	2,4	5,0	16,6	31,0	12,9	12,9	0,7	8,8
Hellisheiði (black)	g	11	48	63	65	81	155	356	1560	1900	406	277	78	–
	pct	0,2	1,0	1,3	1,3	1,6	3,1	7,1	31,2	38,0	8,1	5,5	1,6	–
Hellisheiði (red)	g	60	55	97	113	119	125	222	719	1359	715	778	452	186
	pct	1,2	1,1	1,9	2,3	2,4	2,5	4,4	14,4	27,2	14,3	15,6	9,0	3,7
Seyðishólar	g	166	92	88	78	106	168	529	2023	1375	209	166	–	–
	pct	3,3	1,8	1,8	1,6	2,1	3,4	10,6	40,4	27,5	4,2	3,3	–	–
Kálfhólar	g	130	59	55	55	76	152	454	996	1158	676	745	357	87
	pct	2,6	1,2	1,1	1,1	1,5	3,0	9,1	19,9	23,2	13,6	14,9	7,1	1,7
Tjarnarhólar	g	105	65	118	156	157	153	218	469	864	614	918	972	191
	pct	2,1	1,3	2,4	3,1	3,1	3,0	4,4	9,4	17,3	12,3	18,4	19,4	3,8
Vestmannaeyjar	g	62	49	79	141	290	584	1111	1994	678	12	–	–	–
	pct	1,2	1,0	1,6	2,8	5,8	11,7	22,2	39,9	13,6	0,2	–	–	–
Hekla (HAF)	g	32	7	24	40	94	166	711	1726	1821	267	86	26	–
	pct	0,7	0,1	0,5	0,8	1,9	3,3	14,2	34,5	36,4	5,4	1,7	0,5	–
Hekla Sandá (coarse)	g	104	50	67	167	704	1530	1385	768	219	6	–	–	–
	pct	2,1	1,0	1,3	3,3	14,1	30,6	27,7	15,4	4,4	0,1	–	–	–
Hekla Sandá (fine)	g	282	104	203	427	1022	1914	811	207	30	–	–	–	–
	pct	5,6	2,1	4,1	8,5	20,4	38,3	16,2	4,2	0,6	–	–	–	–
Skógasandur	g	154	155	277	443	549	1018	1567	771	66	–	–	–	–
	pct	3,1	3,1	5,5	8,9	11,0	20,4	31,3	15,4	1,3	–	–	–	–
Mýrdalssandur	g	196	198	305	429	785	1131	1180	688	88	–	–	–	–
	pct	3,9	4,0	6,1	8,6	15,7	22,6	23,6	13,8	1,7	–	–	–	–

Table 6 Investigation of water absorption

Deposit	Bulk density in kg/m³	Weight of used material in g	Volume of used material in cm³	Water absorption in g / in pct by vol. after 3 h	4 h	19 h	20 h	22 h	48 h	49 h	50 h	69 h	72 h
Svartsengi (black)	1233	863	700	223/31,9			234/33,4					246/35,1	
Svartsengi (red)	1223	856	700	222/31,7			227/32,4					235/33,6	
Óbrynnishólar (black)	840	940	1000		289/28,9			311/31,1			333/33,3		
Óbrynnishólar (red)	850												
Hellisheiði (black)	786	550	700	219/31,3		225/32,1				230/32,9			
Hellisheiði (red)	855	599	700	204/29,1		212/30,3				219/31,3			
Seyðishólar	928	628	1000	344/34,4				362/36,2					380/38,0
Kaífhólar	559	601	700	223/31,9			234/33,4					246/35,1	
Tjarnarhólar	777	544	700	235/33,6			236/33,7					240/34,3	
Vestmannaeyjar	840	588	700	177/25,3		178/25,4			182/26,0				
Hekla (HAF)	541	379	700		249/35,6			276/39,4					302/43,1
Hekla Sandá (coarse)	447	447	1000	405/40,5		457/45,7				495/49,5			
Skógasandur													
Mýrdalssandur	966	676	700		208/29,7			214/30,6					222/31,7

Table 7 Investigation of pozzolanic effect

Deposit	Density in kg/m³		Compr. strength kp/cm²		Bend. strength kp/cm²	
	single	average	single	average	single	average
Seyðishólar	1470	1480	51,6 / 54,2	61,2	4,5	4,1
	1490		73,2 / 70,6		3,8	
	1480		63,8 / 54,0		*	
Hekla HAF	1360	1370	108,8 / 110,8	101,4	0,4	0,5
	1380		103,6 / 98,0		0,8	
	1370		93,5 / 93,5		0,3	
Óbrynnishólar	1410	1410	25,2 / 24,0	24,6	1,2	1,2

* the specimen has broken during encasing

Table 8
Estimated quantity of material in the deposits and distances of transport

Deposit	Distance from Reykjavik in km	Distance from nearest harbour in km		Estimated quantity in million m³
Svartsengi scoria	50	Grindavik	3	0,1 - 1
Óbrynnishólar scoria	25	Hafnarfjördur	15	1 - 3
Hellisheiði scoria	30	Reykjavik	30	preserved
Seyðishólar scoria	75	Þorlákshöfn	55	~ 20
Kálfhólar scoria	75	Þorlákshöfn	55	~ 10
Tjarnarhólar scoria	75	Þorlákshöfn	55	negligible
Vestmannaeyjar scoria	250	Heimay	3	min. 3
Hekla HAF pumice	140	Þorlákshöfn	120	min. 30
Hekla Sandá pumice	125	Þorlákshöfn	105	min. 3
Skógasandur pumice	170	Þorlákshöfn	150	min. 1
Mýrdalssandur pumice	205	Þorlákshöfn	185	min 500

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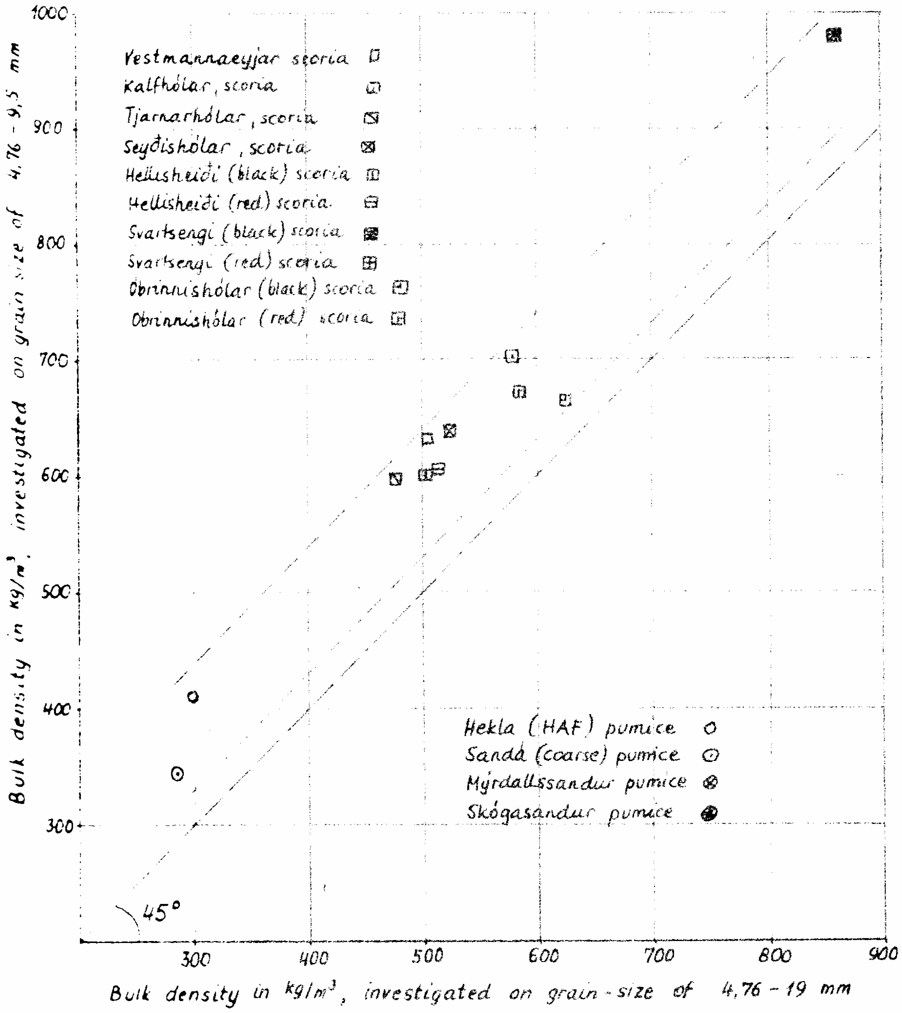

Figure 2 Relationship between bulk densities investigated on grain-sizes of 4,76 - 9,5 mm and 4,76 - 19 mm

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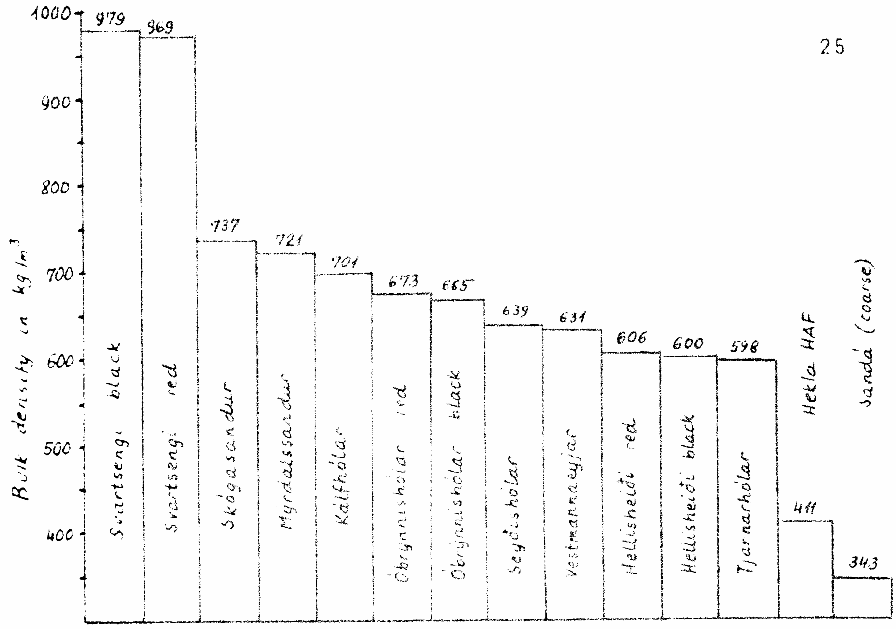

Figure 3 Results of bulk density investigations on grains of 4,76 - 9,5 mm

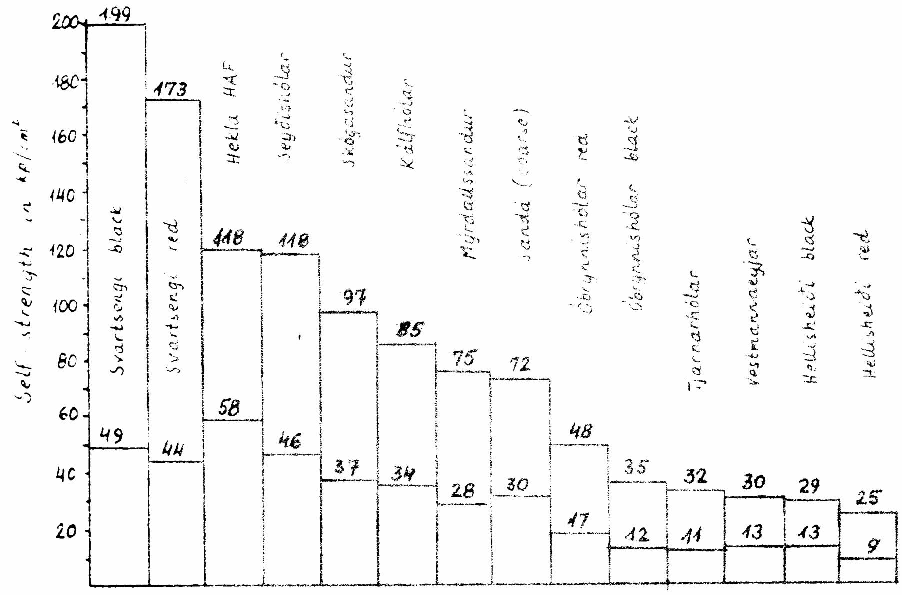

Figure 4 Results of self-strength investigations on grains of 4,76 - 9,5 mm

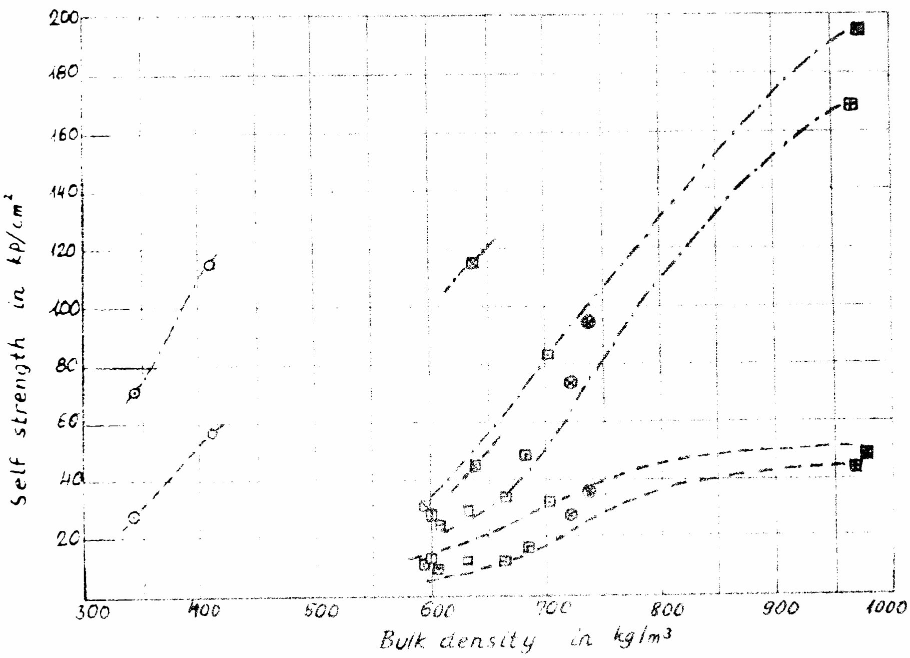

Figure 5 Relationship between bulk density and self-strength of the investigated lightweight aggregates

Legend :

Hekla HAF pumice

Sandá (coarse) pumice

Mýrdallssandur pumice

Skógasandur pumice

Vestmannaeyjar scoria

Kalfhólar scoria

Tjarnarhólar scoria

Seyðishólar scoria

Hellisheiði (black) scoria

Hellisheiði (red) scoria

Svartsengi (black) scoria

Svartsengi (red) scoria

Óbrinnishólar (black) scoria

Óbrinnishólar (red) scoria

Grain size : 4,76 – 9,5 mm

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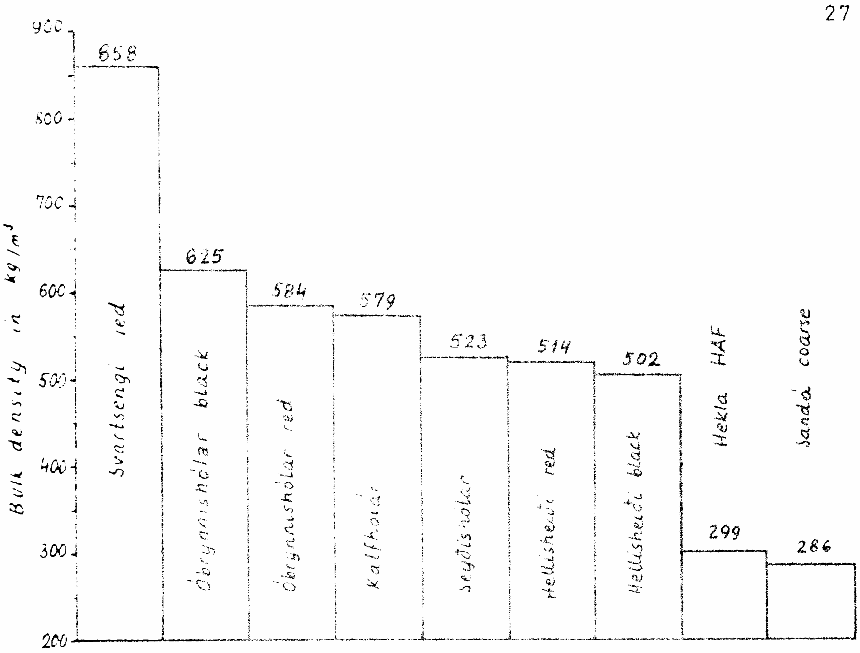

Figure 6 Results of bulk density investigations on grains of 4,76 - 19,0 mm

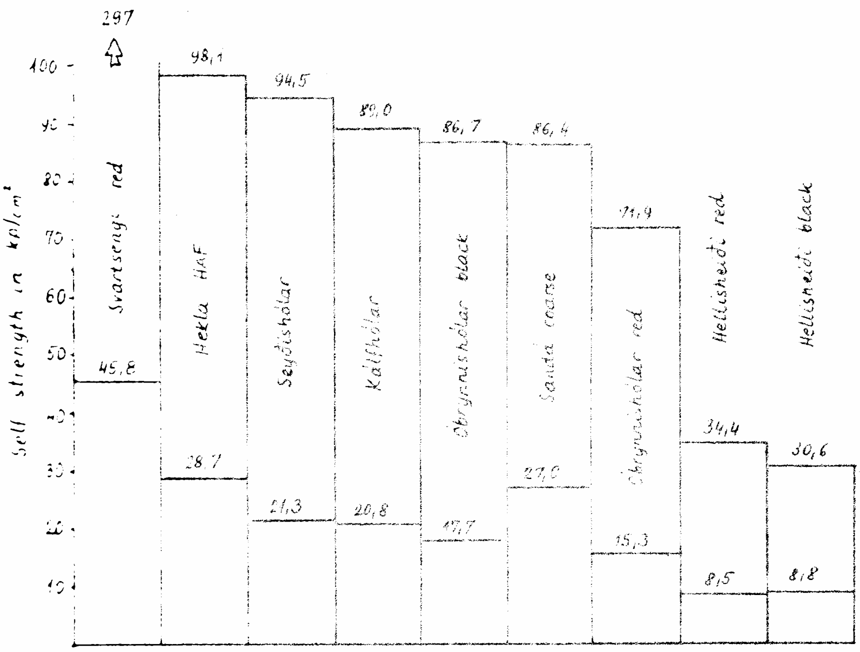

Figure 7 Results of self-strength investigations on grains of 4,76 - 19,0 mm.

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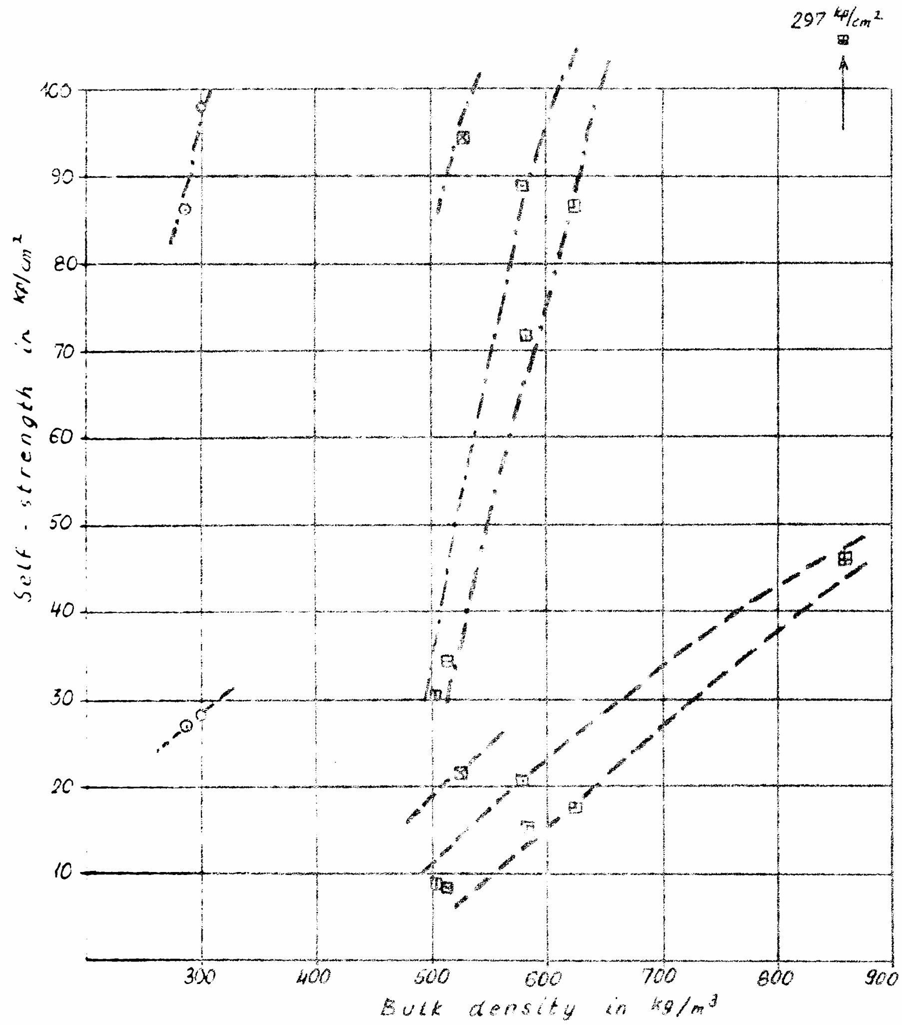

Figure 8 Relationship between bulk density and self-strength of the investigated lightweight aggregates

Grain size: 4,76 - 19 mm

Legend can be seen in Figure 2

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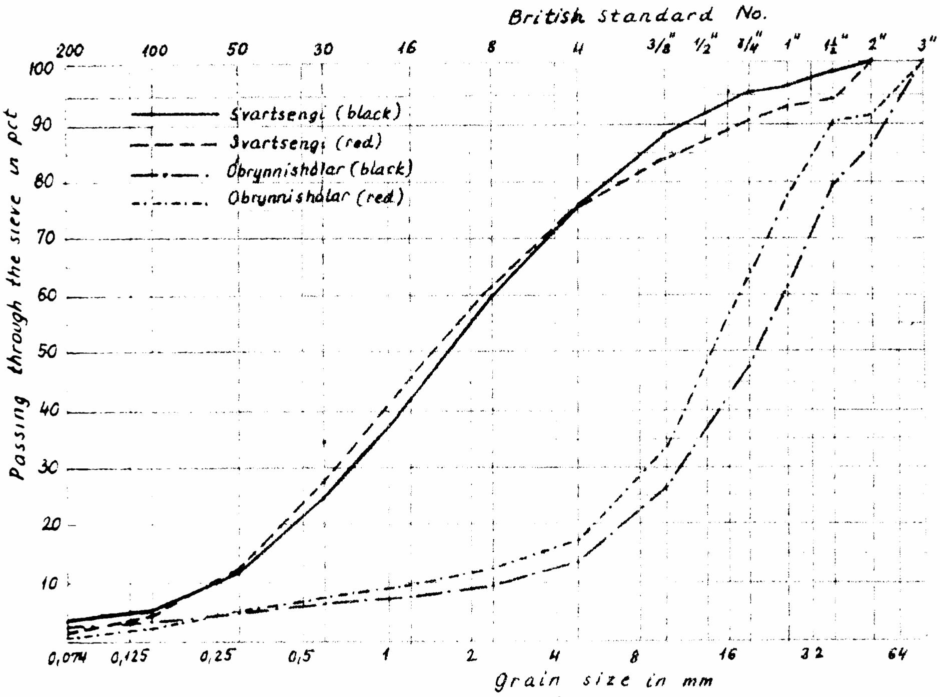

Fig. 9 Grading of scoria from Svartsengi and Óbrynnishólar

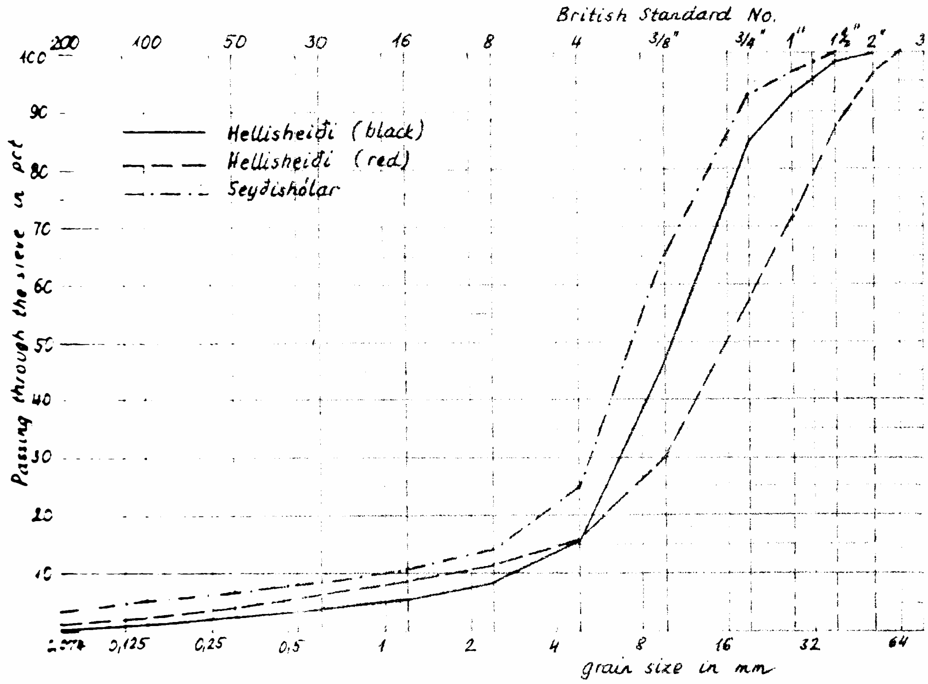

Fig 10 Grading of scoria from Hellisheiði and Seyðishólar

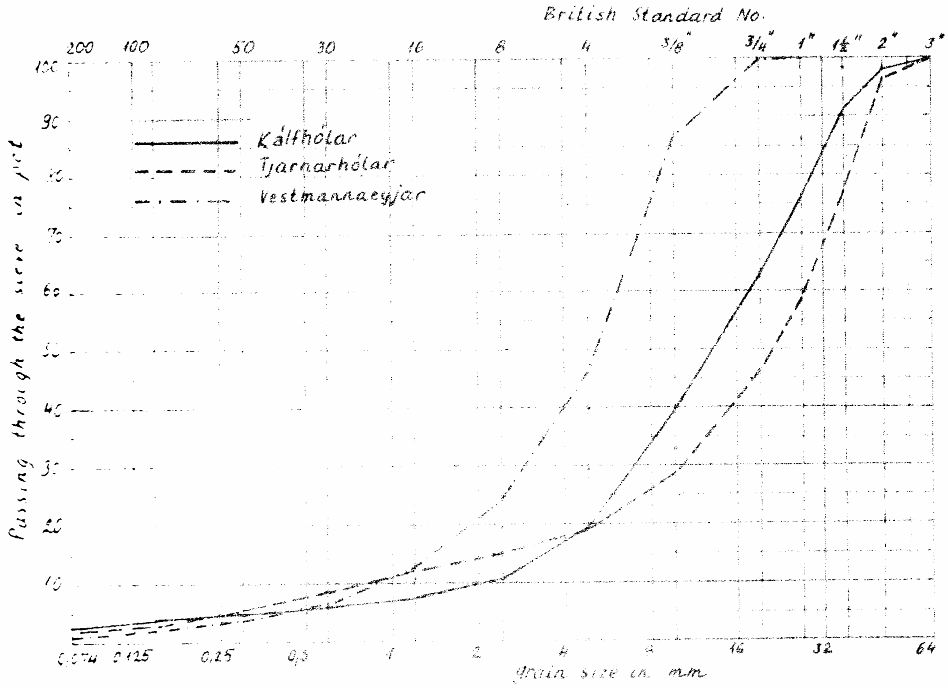

Fig 11 Grading of scoria from Kálfhólar, Tjarnarhólar and Vestmannaeyjar

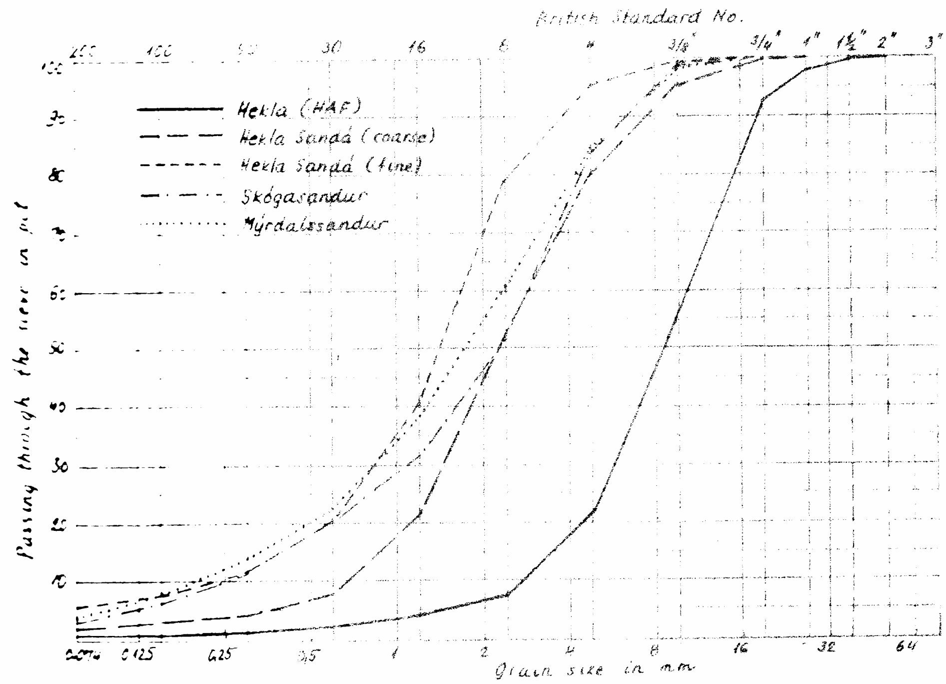

Fig 12 Grading of pumice from Hekla and Katla territory

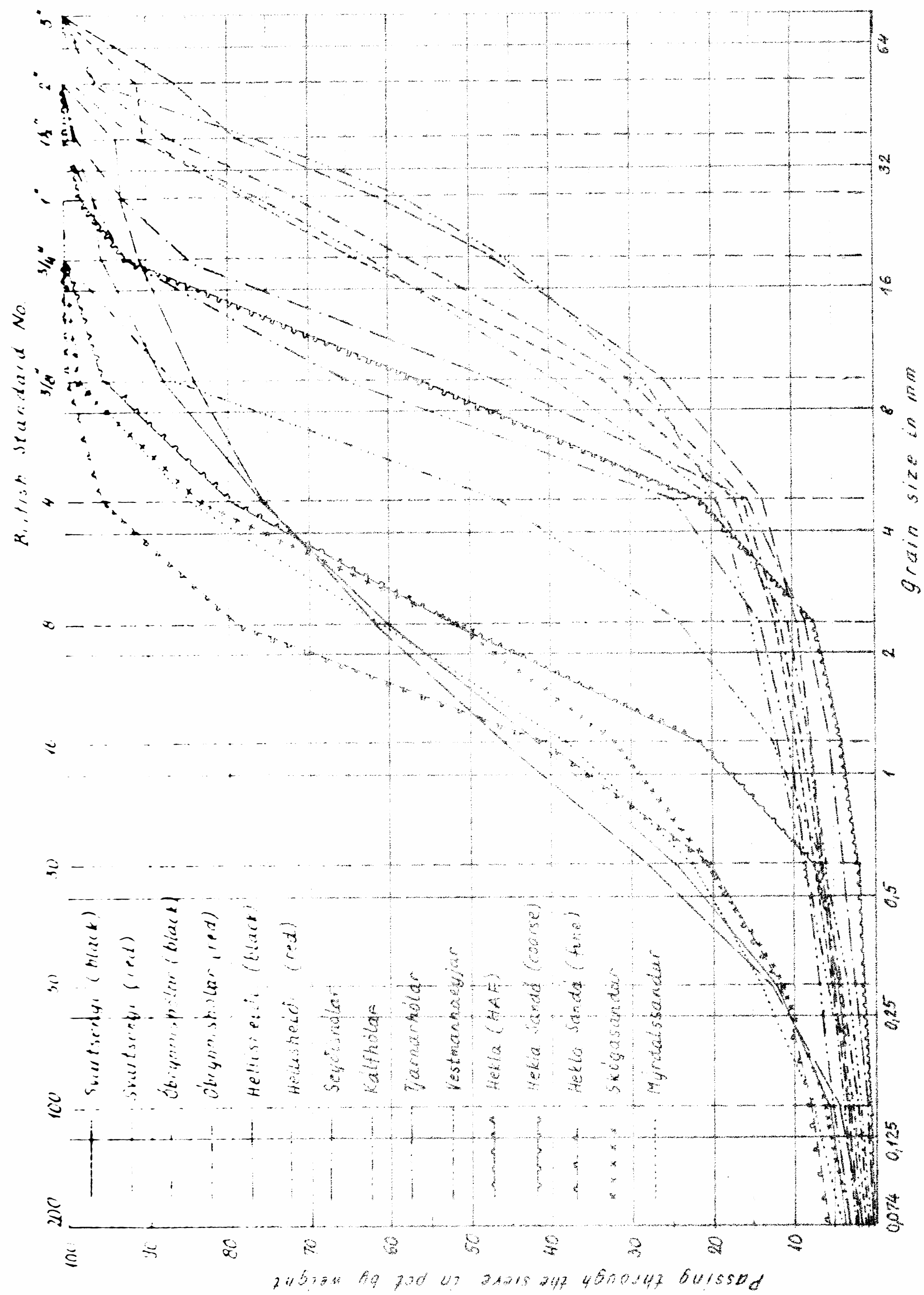

Fig. 43 Summarized results of grading investigations

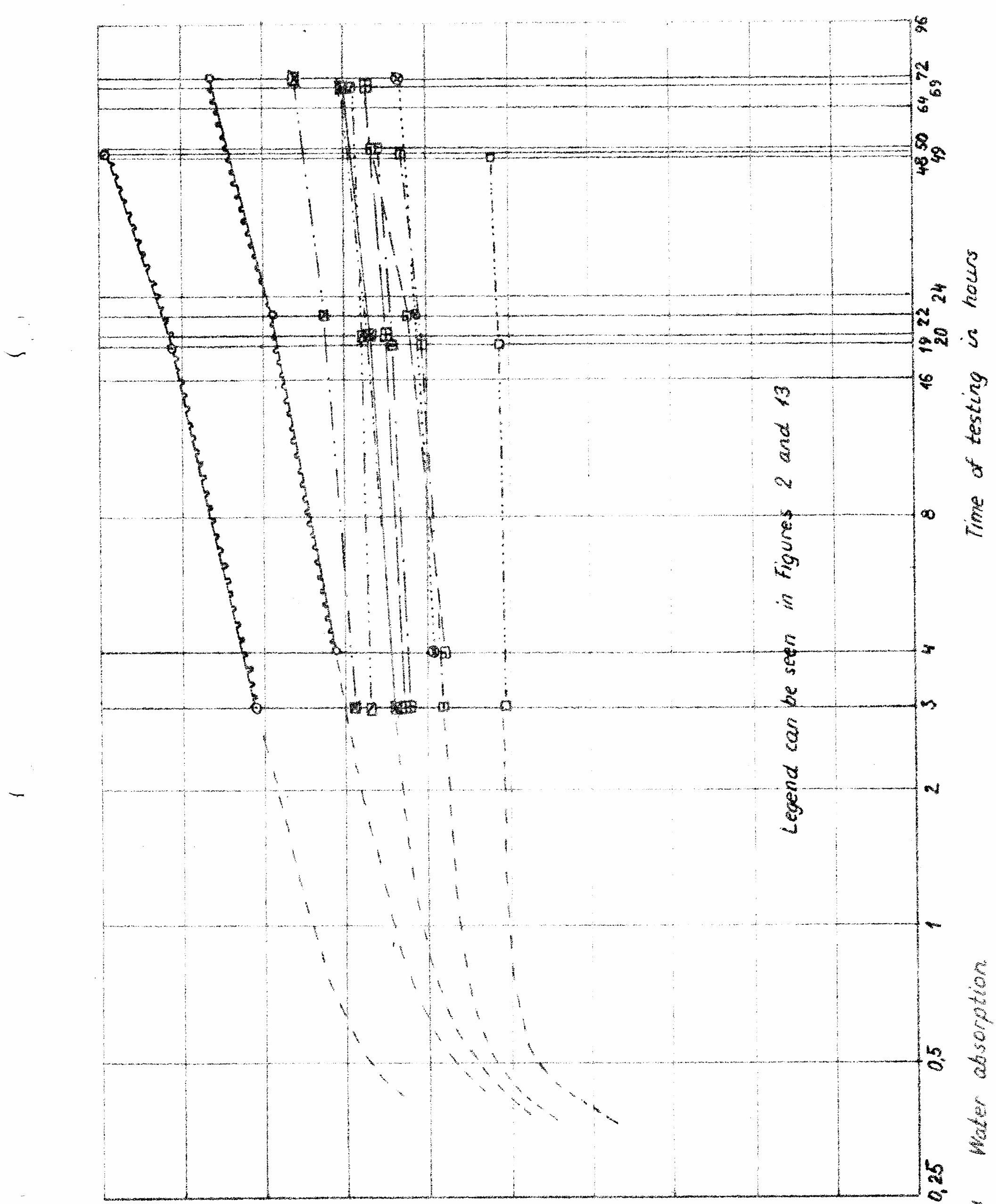

Fig. 14 Water absorption.